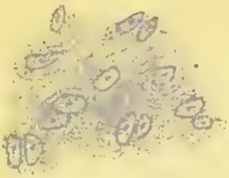
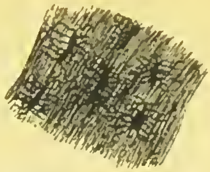
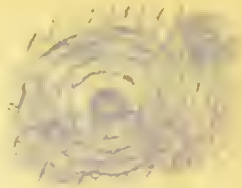
ELEMENTARY PHYSIOLOGY
FOR STUDENTS.



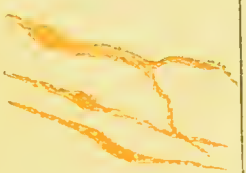
Hyaline Cartilage.



Bone Cells.

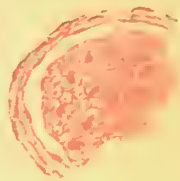


Section of Bone



Unstriped Muscle Cells.

Plexus of unstriped Muscle Cells.



Section of Nerve with Perineurium.

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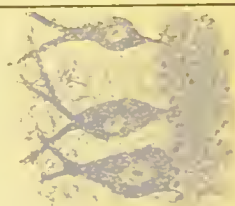
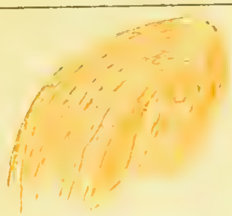
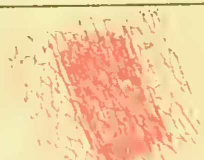
Central Canal of Spinal Cord.



Section of Cerebellum.



Paccinian Corpuscle and Central Nerve.

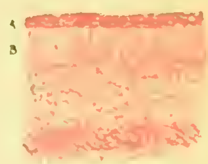


Artery in Perivascular Sheath.

A Mucous Gland.

Section of Stomach Wall. (Cardiac end.)

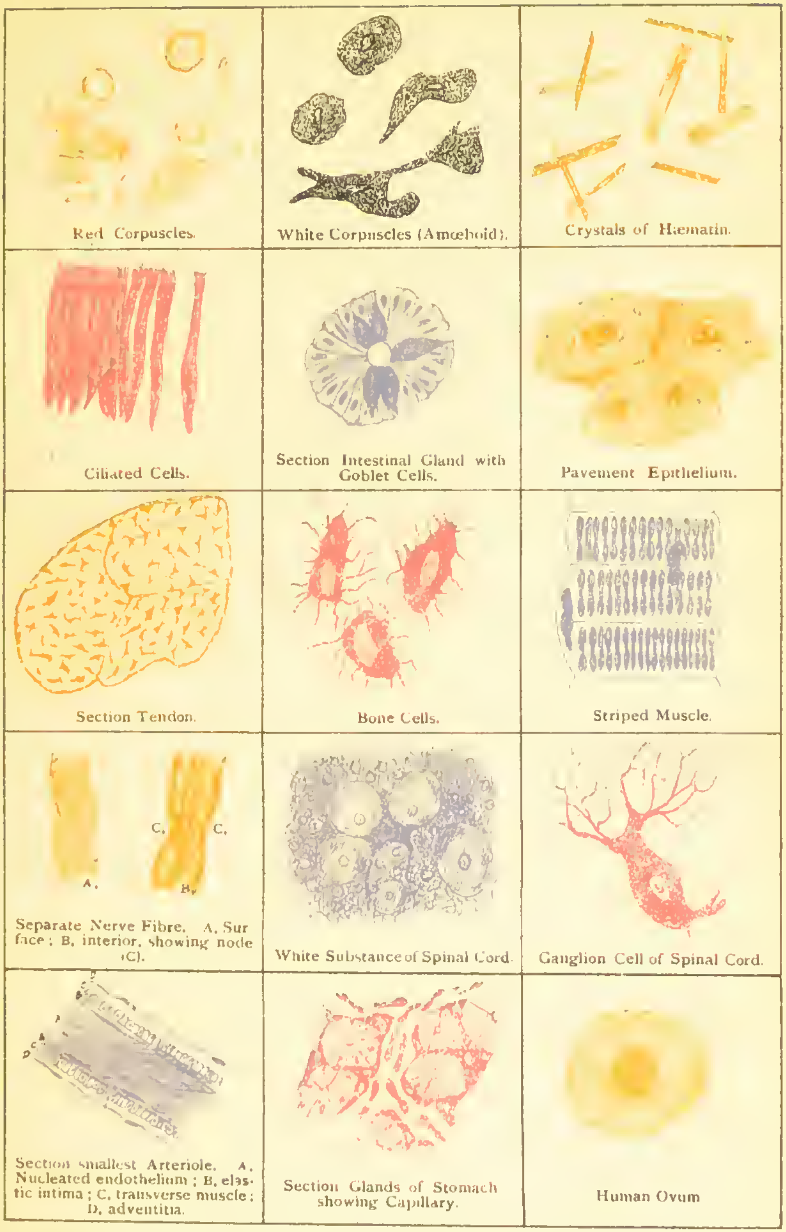
Root of Hair.



Part of Retina. A, Choroid, B, rods and cones.

COMPARATIVE SIZES OF VARIOUS TISSUES AND STRUCTURES UNIFORMLY MAGNIFIED TO 80 DIAMETERS.

The best microscope powers to show Tissues this size are :—		OBJECTIVE.	EYEPIECE.
	English	Half inch	A
	Zeiss	AA	3
	Hartnack... ..	4	3



COMPARATIVE SIZES OF VARIOUS TISSUES AND STRUCTURES UNIFORMLY MAGNIFIED TO 240 DIAMETERS.

		Objective.	Eyepiece.
The best microscope powers to show Tissues this size are :—	English	Quarter inch ...	... B
	Zeiss	CC	... 4
	Hartnack	5	... 4

Elementary Physiology

for Students.

BY

ALFRED T. SCHOFIELD, M.D., M.R.C.S., &c.,

Author of "Physiology for Schools," "Manual of Hygiene," &c. &c.

With Two Coloured Plates and other Illustrations.

CASSELL & COMPANY, LIMITED:

LONDON, PARIS & MELBOURNE.

1892.

PREFACE.

THIS small manual is an attempt to present to the student of Physiology the leading facts of the science in a fuller way than is generally found in a work of this size.

This has been accomplished mainly by (1) omitting long discussions of rival views and theories, which are a doubtful help to the commencing student, to whom dogmatic teaching is of most value; (2) by omitting long lists of names (generally polysyllabic) and authorities; and (3) by introducing very sparingly detailed descriptions of the various complicated machines by which the results recorded have been obtained. The principle that has guided the author in selecting material for the work has been that expressed in these weighty words of Virchow: "Whoever speaks or writes for the public ought, in my opinion, doubly to examine just now how much of that which he says is objective truth. He ought to try as much as possible to have all inductive extensions which he makes, all conclusions arrived at by the laws of analogy, however probable they may seem, printed in small type under the general text, and to put with the latter only that which is objective truth."

It has not been possible to carry out this wise suggestion literally in all cases, but it has been the endeavour, while presenting concisely the latest facts in this science, to omit

doubtful theories; or, at any rate, to insert them in "small type." For much in the book the author is deeply indebted to a master of the science, whose luminous teaching first gave him, many years ago, a love of Physiology. It is hoped that the brief and unadorned style necessary to so small a manual may not prevent any from finding the book of some substantial help in the study of this fascinating science.

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LIST OF ILLUSTRATIONS.

ELEMENTARY PHYSIOLOGY FOR STUDENTS.

CHAPTER I.

THE PHENOMENA OF LIFE.

I. PHYSIOLOGY.

Physiology is one of the subdivisions of Biology, and concerns itself with the *functions* of life. *Morphology* and *Embryology*, the other two subdivisions, treat respectively of the *forms* and *development* of life. Definition.

Physiology also deals with the five leading features of life—*birth*, *growth*, *development*, *decay*, and *death*. Five features of life.

Birth simply marks the definite commencement of separate existence, and is an essential of every living thing, in that it implies that all life, without exception, is got by inheritance; and never since it first originated, as far as we know, has commenced *de novo*. Before the days of exact research, the contrary was believed to be true, and the presence of life in decaying animal and vegetable matter was supposed to prove that life could exist without previous life. It is needless now to show how the progress of science proved this to be a fallacy, and that every form of the lowest bacterium or smallest animal did and could only spring from a parent of the same species. The theory of spontaneous generation is now everywhere proved to be false, and where adequate care is taken to exclude life Birth.

from animal matter, no decomposition takes place, and no living forms are found.

Growth.

Growth is not confined to living beings, but in them it takes place in a totally different way from that in the inanimate world. In a crystal, for instance, or in rock formation, growth takes place by the mechanical addition of layer after layer, the mass itself taking no part in the process; and it continues, moreover, indefinitely. In a living organism growth is the result of change and increase in every part throughout the being, and this growth has strict limits beyond which it cannot continue.

Development.

Development is a quality that has no parallel in the inanimate world. As growth is an increase in quantity, so development is an increase in quality, being the perfect adapting of means to ends, of machinery to work, through continual use. Every organ of the body, including the brain, is thus developed by use, and becomes not only larger, but stronger and better adapted for its work.

Decay.

Decay is now understood to be a constant manifestation of life. It used to be thought that life consisted in a power to resist decay, and it was only when life ceased that decay commenced. It is now found, not only that decay is an incessant accompaniment of life from birth, but that it is positively more active during life than afterwards. It is true that during life the effects of decay are not obvious, as, on the other side of the balance, the opposite force of repair or growth serves as a counterpoise to keep the body in "dynamic equilibrium:" but when the summit of life is passed, repair gets more and more feeble, and at last ceasing in death, leaves the field free for the ravages of decay. Life is not, then, a power that resists decay, but, on the contrary, is a force *that cannot be manifested without it;* every movement, every look, every

thought, involving the decay and destruction of a certain amount of body tissue.

Death.

Death is a phenomenon quite peculiar, and necessarily so, to life; for it is obvious that nothing can cease to live save what has lived. But it is not so much an interruption of life as the final attainment of an end which was held steadily in view from the beginning, and towards which every act of life tended. Exactly as every beat of an eight-day clock is a step towards the final running down of the weights, which is definitely arranged to take place at the end of eight days, so every movement of the body, and every day that it exists, is a step towards that end for which it was constructed; every body being made, exactly like a clock, to run a definite time. Of course it may be stopped before (as a clock with the finger) by disease or accident. No cause is, however, known why, when the machinery has become perfectly well balanced, and decay and repair are equal, it should not continue so indefinitely, seeing it is self-repairing; instead of wasting away after a certain number of years.

2. LIFE.

What is Life?

What special power, then, has this life to present such an orderly sequence of phenomena peculiar to itself? What, in short, is life?

Consider for a moment the difference between an egg that is fertile and can produce a chicken and thus contains life, and one that cannot; for though both are organic compounds, and both produced by living beings, nevertheless they are not the same.

At first sight both eggs appear alike, and, apart from external force, no difference can be seen; both will go bad, and the living egg will have no advantage over the dead one. But let heat, which is a most potent force, be applied to both, and they will soon begin to differ; and it will be seen in a few

days that the "life" in the one egg is a capacity to appropriate and use this force, and eventually to manifest it in the production of a chick; which chick, in common with all other living beings, must continue to appropriate force in the shape of heat, light, and food, or the life ceases. In the other case the same heat applied to a similar organic substance that does not possess this power or life thus to use it, simply hastens decay and decomposition.

Life, then, is a special power inherent in the living cell to use external force and manifest it in special phenomena, but it is not an independent physical force or energy, being, on the contrary, wholly dependent for its manifestations on the common forces of nature.

Animal and Vegetable Life.

The difference between *animal* and *vegetable* life is simple and important. Vegetable life can appropriate force from inorganic matter. It decomposes carbonic acid gas and ammonia, and then stores up the carbon and nitrogen as force to be used hereafter. This life principally consists in the *storing of force* rather than in its manifestation. Animal life, on the other hand, takes these stores, and in reducing them again to their simple elements of carbonic acid and ammonia evolves and uses up the force they contain. Animal life, therefore, largely consists in the *manifestation of energy*.

A vegetable may be compared to a hard-working father accumulating large stores of wealth, while the animal rather resembles the spendthrift son who uses it all.

Just, however, as it may be noted that large parts of vegetables (the layers of bark, etc.) are lifeless, and are subject to such slow changes as to resemble minerals, so within animal bodies many processes are performed by which force is stored and not expended, animal bodies therein closely resembling vegetables.

The animal not only thus uses the force of the vegetable world, but is absolutely dependent upon it, for it is not able

to use force directly from the inorganic or mineral world, but only after it has been stored and changed by the organic or vegetable.

Movement.

It may be thought strange that no mention has yet been made of movement as an inherent quality of life, and particularly and obviously of animal life. The truth is that the mere fact of an animal being able to move is not more wonderful than that a steam engine can do the same, and hence movement is no special property of life.

The difference lies in the way in which the transformation of force is effected; simple and easy to trace in the one, in its steps from the energy in the sunlight transferred to the early vegetation, stored up in our earth as coal, this again passed on to the water as heat, and this as steam passed on to the engine, and resulting in movement by its expansion; but in the other the actual transformation is at present inscrutable. What is known on the subject will be spoken of later on.

3. THE EXTERIOR OF THE BODY.

An Upright Man.

Having briefly discussed the question of what life really is, and what are its principal features, and having taken a survey of its various stages, let us now examine an individual as he stands erect before us, and see what we can learn of the human body from an external view.

The Head and Face.

Notice the shape of the head, the large proportion the brain —which occupies the whole of the head (Fig. 1) behind and above a line drawn across the eyebrows and continued to the lobes of the ears—bears to the face, greater than in any animal. Observe that the forehead and the face lie as nearly as possible in the same plane, and the line from the forehead, with that from the ear to the lower edge of upper teeth, forms almost a right

angle, an arrangement only suited for the erect attitude, and obviously most inconvenient if man went on all fours, when "he could see and smell nothing but the ground" (Holden). As it is, his eyes can command the greatest possible range of vision, their scope being only limited on the inner side by the bridge of the nose, when vision is taken up by the fellow-eye. Observe the eyebrows above, keeping the "sweat of the brow" from deluging the eyes. The eyes should, for beauty, be deeply set, prominent eyes being never seen in ancient art. The nose, too, is not placed. as in animals, so as to scent odours in advance, which to them is of the greatest use, but so as to receive odours from below, and especially of all food going into the mouth. The mouth, again, to man is of as much value for articulation in speaking as for eating, and hence the jaws are not prominent, but the cavities within are specially arranged for the reception and conduction of sound.

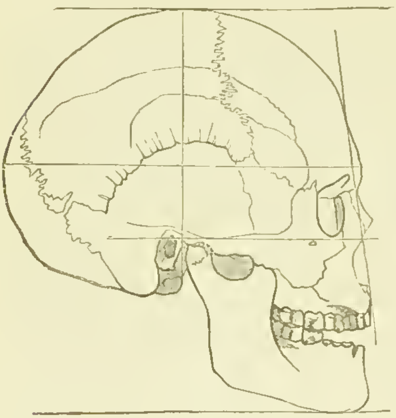


Fig. 1.—European, Skull showing Facial Angle of 75°.

Study finally the unique power of expression that lies in the muscles of the face. The science of physiognomy is most valuable and interesting, for undoubtedly these facile muscles get insensibly moulded by the passions and habits of the man, whose character can be far better read by the lines round his mouth than by the so-called "expression" of the eye.

The ear, the great beauty of which is its small size and perfect lobe, is not made, as in animals, to turn forwards or backwards to catch distant sounds, man having other means

of protection from his enemies and of providing his food than the faculties of scent and hearing.

Observe the lofty forehead, sign of intellect (contrast the head of Shakespeare with the head of one of the Georges), the bright eye of intelligence, the well-formed nose of strong character, the firm mouth, and the square chin of decision.

The Neck.

Now look at the neck. Note how it is completely formed of muscles (flesh) everywhere but at the throat in front, where you see the prominent "Adam's apple," the front of the larynx that contains the voice.

The Trunk.

Look now at the body (Fig. 2), and notice generally how all its complicated framework and tissues are hidden and so blended as to present but one harmonious whole. Observe that the chest is much broader than it is thick, an arrangement only found, among mammals, in man and some of the highest apes. This arrangement throws the arms much wider apart than the legs, giving them a much wider range for grasping, but making them weak and useless for walking. In other animals, on the contrary, the upper part of the chest is narrow, to allow the forelegs to come close together and stand directly under the trunk they support. Notice the bony framework of the chest, which is formed by the ribs and breastbone. Observe that if these were continued all the way down, we could not stoop, and could hardly move. The lower half of the body, therefore, is protected instead by a firm but yielding wall of strong muscles; added to which are some elastic fibres. In

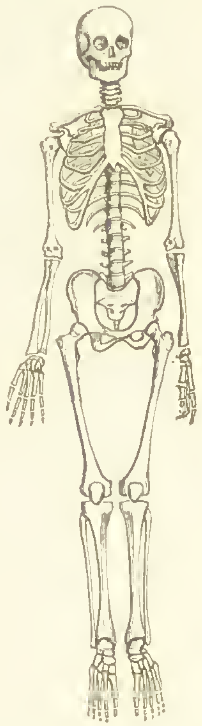


Fig. 2.—Skeleton with legs apart. When together, the slant of the thighbones is clearly seen.

animals who walk on all fours these fibres form a complete elastic belt to support the body. Note, moreover, that the heaving of the chest and beating of the heart are all conducted within the thorax, so that the three great organs necessary to existence—the brain inside the skull, the lungs and the heart beneath the ribs—are thus entirely protected from all ordinary injury.

We have alluded to the bony framework, and we may note one or two facts about it now. If we divide the body into seven parts—four limbs, trunk, and head and neck—we find each part contains about thirty bones (counting the ribs in pairs), there being about two hundred in all the body. These bones form the framework of the body, and on their length depends the height of the man.

The Tissues of the Body.

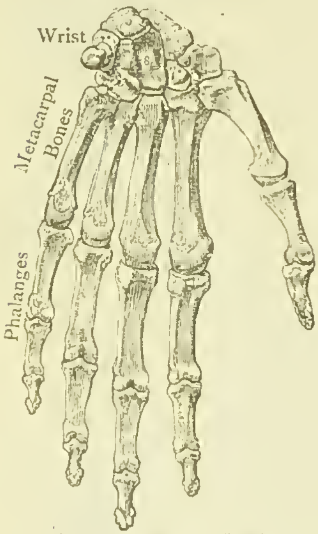


Fig. 3.—Bones of Hand.

The Forearm and Hand.

Observe, now, the arm generally: The looseness of the shoulder-joint, adapted for universal movement, but not to sustain the weight of the body. Note that the forearm does not fold on the upper arm, but to its inner side towards the mouth, a more useful position. Look at the hand and wrist (Fig. 3), which alone contain some twenty-seven bones. The supple strength of the wrist: the value of the thumb, not placed in a line with the other fingers, but in advance of them, and so as to touch them all; the nails arranged to support the finger-tips, and yet not interfere with their touch, are worthy of note. The hands are marvels of precise and adapted echanism, capable, not only of executing every variety

o work, of expressing many emotions of the mind, but of executing its orders with inconceivable rapidity.

Take, now, a wider view of the beauty of the human figure. Let the person stand with feet together and outstretched arms. His breadth is now equal to his height, and the four sides of a perfect square will in a perfect figure touch the soles of the feet, the crown of the head, and the tips of the fingers. Of the height, the hand should measure one-tenth part, the forearm one-quarter, the head one-eighth, the face one-tenth, the leg (from knee-cap to foot) the same, while the greatest width of the chest should measure one-fifth, the least one-sixth; the breadth of the nostrils should equal the length of the eye; the mouth should be half as long again; the forehead should be the same breadth as the nose is long. Coming down the trunk, observe that the rugged outlines in statuary in the male figure are all due to muscular development, indicating strength; while the smoother curves of the female figure are due to the preponderance of fat. Observe, by the way, how every part is so moulded that those forms, the commonest in human designs and machines, straight lines and angles, hardly exist in the body at all. In the erect position one of the beauties of the body is its perfect balance, and the way it conforms to the laws of gravitation.

Proportions of the Body.

Notice, now, that the waist is a natural, and not an artificial, product, but that it forms, as we have said, not an abrupt angle, but a hollow curve from above downwards; and an ellipse, and not a circle, horizontally. Observe that in the male figure the shoulders are rather broader, and in the female slightly narrower than the hips; so that the male form somewhat resembles a single inverted cone, the female a double one. Notice how broad and strong the haunch-bones are as compared with animals, since it is only in the erect position they have largely to bear the weight of the internal organs.

The Waist and Back.

Now, before looking at the legs, turn to the back, and observe the spring given to the figure by the beautiful double curve of the backbone, so admirably adapted, as we shall see, to break shocks going to the brain. In the infant the spine is quite straight, and no animals possess the spinal curves we do, which are only required in the erect position. As the child breathes, this yielding spine is forced out between the shoulders and forms the first curve. When it learns to walk, the forward curve in the loins is needed, and the compensating forward curve of the neck, to balance the body (Fig. 4).

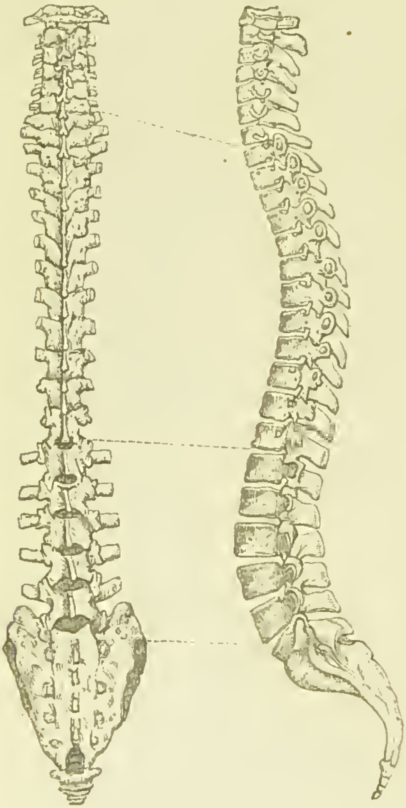


Fig. 4.—The Spine.

The Legs.

And now look at the legs (Fig. 5). In the first place, in proportion to the body or trunk, they are longer than any other mammal's, not even excepting the kangaroo. As Holden has remarked, their great length prevents their being adapted for locomotion in any but the erect attitude. Contrast them with the short and broad legs of the three highest apes, the gorilla, chimpanzee, and ourang-outang. Watch one of these apes walking, and you will find he supports himself alternately on the right and left knuckles, as well as on his feet.

Observe now the thigh-bones, how they slant inwards from the hips, where they are eighteen inches apart, to the knees, where they touch. (Fig. 2.) This slant is peculiar to man, and gives great freedom of movement to the legs, and greater power and leverage to the muscles; but the chief value of the width at the hips, as compared with the knees,

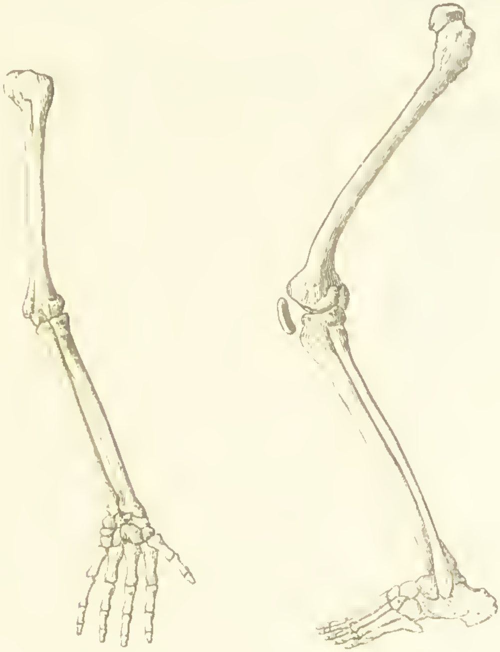


Fig. 5.—The Bones of Leg and Arm compared.

besides allowing room for the lower part of the limbs, is that it allows room for an arch that helps to break the shocks to the brain. The length of the thigh is also peculiar to man, and is in great contrast to the comparative shortness of the corresponding bone of the arm. Hence in man the fingers only reach to the middle of the thigh, while in the chimpanzee they reach to the knee, and in the ourang-outang

to the ankle. The calf of the leg owes its great size to its enormous muscles, which are sufficiently strong to easily raise the entire weight of the body, as when standing or walking on tip-toe.

The Foot.

Now look at the foot, which is broader and stronger and larger in proportion to the body than that of any other animal; hence a man can stand on one leg, which no other mammal can do. Observe the strong and elastic double arch of the foot that bears the whole body weight, and which we will examine more closely in the next chapter (Fig. 6).

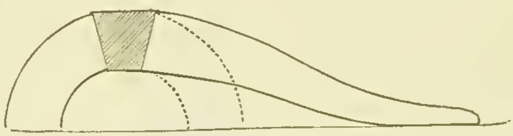


Fig. 6.—Diagram of Arch of Foot.

Symmetry.

In the body almost everything is paired, right and left, giving it symmetry. There are but five central bones; two in the head, one in the throat, and the breastbone and backbone (or spine); and there are but five single muscles, all the rest—out of many hundreds—being in pairs. In the interior, where economy rather than symmetry is required, it is not so; there being as many single organs as there are double.

The Spine.

Before we leave this external view of the man, and examine the interior, notice once more the part played by the spine—the graceful poise of the head and firmness of the neck, the easy grace of the carriage, which all depend upon a strong, straight spine and well-developed back muscles. Notice, too, that a well-formed back is not flat, but, viewed transversely, has a double curve, like an old bow, occupied by the firmly-developed spinal muscles, with a well-formed groove in the

middle, running right up to the nape of the neck, where the backbone lies. Viewed longitudinally, the back should not be bowed so as to make it rounded at the shoulders, though it should show the double curve of the spinc. Many ill-formed persons have their chests flat, like ill-formed backs, and their shoulders rounded, like over-expanded chests.

Fig. 7.—The Two Tubes in the Body.

4. THE INTERIOR OF THE BODY.

Leading Divisions.

Even when looking at the exterior of a man's body, we can readily indicate the leading divisions of the interior. In every factory there are three great things to be observed: the boiler that generates the force (steam), the engines, shafts, and strapping by which this force is distributed all over the place, and the machinery which uses it. In man the *body* is the boiler, the *brain and spinal cord* are the engine and shafting, the *limbs and special senses* the machinery to be worked, the steam being the fresh blood and the nerve-force in the brain. The body, then, generates the power, the head takes it up and distributes it through the nerves, and the limbs and senses use it. The limbs are solid throughout, and contain nothing but the machinery requisite for moving them, and the steam-pipes needed to work the machines. It is therefore only in the body and head that we can find the details of how life-force is generated, and how the

functions of life are carried on. The head and spine are the seat of the nervous system; the upper part of the body, or chest, the seat of the respiratory and circulatory system; the lower part, or stomach, the seat of the digestive and secretory systems; and the limbs of the locomotory system.

Another mode of looking at the structure of the body is more anatomical. Man is a member of the Vertebrata. His body has an internal skeleton, of which the chief feature is the central axis or backbone. Considering the skull and backbone as one, the body may be said to be built up of two tubes (Fig. 7), the smaller *posterior* or *neural tube* including the cavity of the skull and the vertebral canal. Within this tube is lodged the nervous centre (or engine) of the body. The *anterior* or *body tube* is much larger, and consists of the face above and the neck and trunk below, and it contains the vegetative systems of life. So that the whole body in section is like an 8 with the lower circle immensely exaggerated (Fig. 8).

Anatomical View.

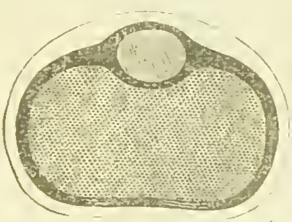


Fig. 8.—Section.

The limbs, of course, are not tubular, and merely form part of the machinery.

Let us now consider how the various parts of the body are worked and controlled.

There are two distinct seats of government in the human body: the one is in the brain, the other is in the very centre of the human body. That in the brain is the human will. It is absolutely autocratic, supreme, God-like in its qualities, and responsible only to the One who gave it. This imperious and imperial human will has absolute control given to it over the animal part of the human life, that is,

Two Governments.

The Will.

over that part that consists in the using of force, which includes the *nervous* and *locomotory* systems and the special senses.

The other government, situated, as we have said, in the lower part of the spinal cord and down the centre of the body, in front of the spine, is of an entirely different order. It is, indeed, a most complete and absolute system of Home Rule. The imperial government of the brain proper has no power over any of its actions; absolute though it may be over its own domain, here it cannot interfere. This home-rule government, then, has full and undisputed sway over life itself, particularly over its vegetable, as distinguished from its animal, form —that is, over the generating and storing of vital force rather than over its usage. Over the latter, indeed, it has some slight control, but only so far as to enable it to carry on the former. We will make this plain. The four systems that lie in the body—the *digestive*, the *circulatory*, the *respiratory*, and the *excretory*—may be termed VEGETATIVE SYSTEMS, being designed for the maintenance and storage of life-force; these, then, are entirely under the control of the involuntary nerve centres.

Sympathetic System.

The Vegetative Systems.

From this division of government, we see that we have no power over the processes or functions of life, our sole concern being rightly to use the forces continually placed at our disposal. We do not digest our food, move our heart, or even our lungs, by any constant and direct effort of will. If, indeed, it were so, and the whole of our bodies were under our own control, its management would so absorb the mind as to leave it no leisure to attend to external affairs at all.

No Control over Life.

Having thus briefly reviewed a few of the features of life and of the human body, we will proceed to examinine it in detail, as follows—

Plan of the Book.

1. The STRUCTURAL TISSUES.

2. The VEGETATIVE SYSTEMS of the anterior or body tube—digestion, circulation, respiration, and excretion.

3. The SYSTEMS OF ANIMAL LIFE of the posterior or neural tube—muscular and nervous.

4. The SPECIAL SENSES and the VOICE.

5. The ORGANS OF REPRODUCTION.

CHAPTER II.

THE ELEMENTARY TISSUES.

I. THE CELL.

THE **Cell** forms the basis not only of Physiology but of Biology; for it is the *Embryological*, *Morphological*, as well as *Physiological unit*. This fact was first established by Schwann.

Definition of a Cell.

The cell from which every part, not only of animals, but of vegetables, is built up, consists essentially of a *nucleated mass of protoplasm* varying in the human body in size, from $\frac{1}{3000}$ inch in the blood to $\frac{1}{300}$ inch in the brain.

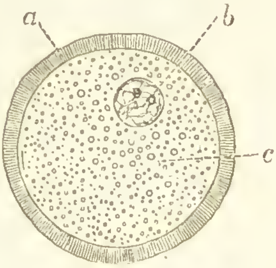


Fig. 9.—A Cell—Ripe Ovum of Cat.
a, Zona pellucida; *b*, germinal vesicle; *c*, protoplasm.

Protoplasm is a transparent, viscid, insoluble, unstable, albuminoid substance, containing 70 per cent. water, that coagulates with heat (130°), and dies when the body is raised to this temperature; the smallest speck of it visible under a high power contains some 2,400,000 molecules. Each molecule is composed of a solid and of three gases, as follows—400 atoms of carbon, 120 atoms of oxygen, 310 atoms of hydrogen, and 50 atoms of nitrogen—with two atoms of sulphur and phosphorus. It often contains other bodies, such as chlorine, fluorine, sodium, potassium, calcium, magnesium, and iron; but the six—C.O.H.N.S.P.—are essential to it. Protoplasm is therefore a proteid, but one of very complicated construction, as befits such a mysterious

Protoplasm.

compound, which contains potentially the elements that eventually form all living beings. The cell on closer examination shows traces of a network in the protoplasm, that may play the part of a sustaining framework (analogous to our skeleton), just as the *nucleus* in the centre, which is of a darker, denser protoplasm (which alone contains phosphorus), represents the source of the cell's energy, or what is analogous to our nervous system. This nucleus may be

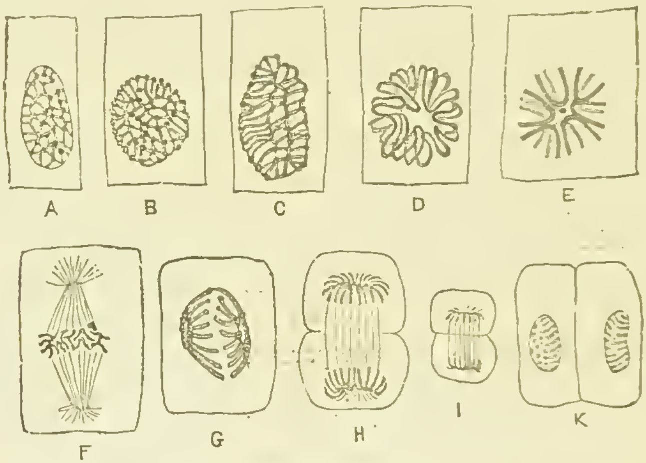


Fig. 10.—Nuclei.

A, Ordinary nucleus of a columnar epithelial cell; B, C, the same nucleus in the stage of convolution; D, the spirem, or rosette form; E, the monaster, or single star; F, a nuclear spindle from the Descemet's endothelium of the frog's cornea; G, H, I, diaster; K, two daughter nuclei.

multiple, and may contain within it one or more small darker spots or *nucleoli*. L. Beale divides a cell into living protoplasm or *bioplasm*, into *formative* material, or food, and *formed* material (cell-wall, etc.), or generating, regenerating, and degenerating parts. (Fig. 10.)

Vital Properties.

A cell manifests its vital properties in that it is born, it grows, it multiplies, it shrivels, and at last dies. During its life it assimilates food, it breathes, it works and rests, it is capable both of spontaneous motion and frequently of locomotion. It can

secrete and excrete substances, and, in short, presents nearly all the physical phenomena of the life of a human being.

Birth.—Cells are produced only from cells, by gemmation or fission. The former, a budding off of a small part of the cell, is rare in man. Fission is a dividing of the whole cell, including always

Birth, Growth, Decay, Death.

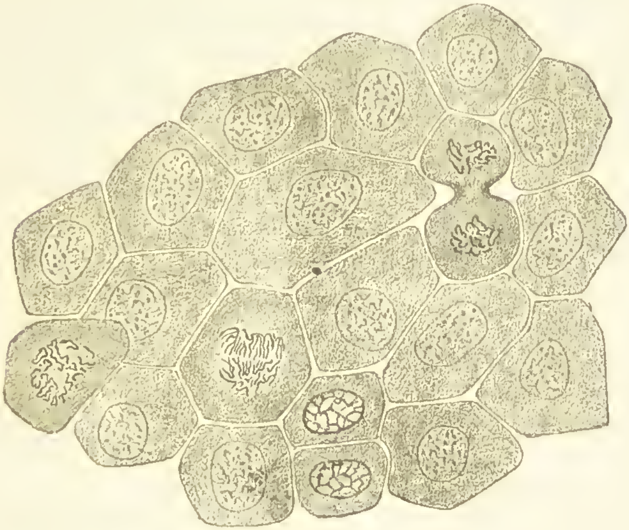


Fig. 11.—Epithelium of Mouth of Embryo Salamander, showing nuclei in various stages of Karyokinesis (Flemming).

a part of the nucleus. The process is very quick, and may take place in a few minutes.

The usual division of the nucleus is complicated, and in four stages called the spirem, monaster, diaster, and dispirem, all designed so as to insure that every part of the nucleus shall be represented in each cell. The stages consist of rod-like arrangements, of definite numbers and in definite order. This is called karyokinesis. When cells multiply quickly the process is only imperfectly formed, often giving the appearance of a direct division of the nucleus. The protoplasm of the rest of the cell divides simply, without these stages. (Fig. 10.)

Growth.—The cell rapidly increases in size up to a certain

definite point, which it maintains during its adult life like a human being.

Decay.—As it gets older it is frequently removed further away from its source of life (the blood-stream), making way for more vigorous life (as in epidermal structures), and gets smaller and flatter.

Death.—After a life of from a few hours to a few days in the skin, it finally dies and dries, becoming a mere horny scale on the surface of the body. Internally its death is frequently brought about by its breaking up, as in the secreting glands.

Assimilation, Respiration, and Work.

Assimilation.—It can take in food from the blood by absorption, or, as in the amœba (or free moving cell), by flowing round the substance of a solid, and thus enclosing and subsequently digesting it.

Respiration.—It inspires oxygen and expires CO_2, which is probably the result of its metabolism.

Work.—This is of the most varied kind, and embraces the formation of every tissue and every product, solid, fluid, or gaseous, of the body.

Rest, Motion, and Locomotion.

Rest.—This work may be intermitted. It is found that in the dark the colour-cells cease to secrete pigment. Muscle-cells have all intervals of rest.

Motion.—This interesting quality of cell-life has only been carefully studied of late years.

Most cells have a limiting membrane or cell-wall, merely consisting of the hardened exterior of protoplasm. This, however, is in many cases capable of assuming the most diverse shapes, known as amœboid movements. If a colourless corpuscle is examined on a warm stage in a saline fluid, it is seen constantly to change its shape by pushing out or retracting some part of its mass.

In vegetable cells, spaces or vacuoles occur within the mass, which

in like manner are so continually changing their shape as to cause the granules in the protoplasm to flow in streams like passengers in a busy street.

Another beautiful form of motion is found in ciliated movements.

The spermatozoa move by the lashing of a long filament at the end of the small cell, by which they can progress for some inches along the generative canal.

The ciliated epithelium—the lining membrane of the air-passages and other parts—consists of cells with a row of from ten to thirty small hairs on the surfaces, which are

Fig. 12.—Amœboid Movement of a White Blood Corpuscle of Man: various phases of movement.

incessantly moved with a distinct lashing motion in one definite direction several times every second.

Locomotion.—Cells may move actively or passively. In the blood the cells are, of course, borne along by the current; but colourless corpuscles seem able to make their way actively about any part of the body at will—if we can speak of will in such bodies. Their movements certainly seem guided by instinct, and are by no means haphazard (Fig. 12).

Recent researches (Metschnikoff) have shown that colourless corpuscles flock to any part of the body where any inflammatory or infectious process is going on (from the leg to the cornea, for example) and there do their best to rid the body of any intruding germs, by swallowing them. Amœboid cells of this type have been seen to work themselves up through the deeper tissues, pushing aside layers of cells in their course, and emerge into the intestine, and then seize on bacilli, and make their way back again after swallowing them.

At first the body consisted of a mass of cells more or less similar in shape and work, but very soon groups of cells began to separate themselves off to build the different structures, on the very principle of division of labour on which the whole of our civilisation is based, and which began so early in the world's history. We will first consider some of these leading varieties, and then the various tissues which they construct.

Division of Labour.

Vegetable cells differ from animal cells in their forms and functions, chiefly as follows:—

Vegetable Cells.

In form:—1. They are always surrounded with a well-developed cell-wall of a non-nitrogenous nature.

2. The contained protoplasm is generally without a nucleus and in two parts—one continuously lining the cell-wall, and the other a reticulated mass filling the interior, the spaces of which are continually changing in shape as the small particles composing it flow in streams in various directions.

3. There is a large amount of intercellular substance in animal tissues which is not needed in vegetables, as the tough cellular wall supplies its place.

In function:—Vegetable cells can build up albuminous material from minerals, as ammonia, iron, and water, with sulphates and phosphates. By means of *chlorophyll*, a green colouring matter they contain, they can decompose CO_2 and retain the carbon and expire the oxygen. They can thus form both starch and albumen. Animal cells possess no such power.

The power of movement is found in many vegetable cells, as in animal cells.

Animal cells, with which we will now concern ourselves, originally all, more or less, of a rounded shape, attain the most varied forms, in accordance with the tissues to which they belong. They may become *hexagonal*, as in many internal membranes: or

Different Cell Shapes.

polyhedral, or *discoid*, as in the blood; or *prickly*, as in the epidermis; or *scale-like*, as in the surface of the skin; or *columnar* (like bricks on end), as in its deepest layers; or *cubical*, as in many organs; or *wedge-shaped*, as in the salivary glands; or *crescent-shaped*, or *branched*, or *stellate*, as in nerve tissues; or *fish-shaped*, forked at one end, as in the ureters; or *canoe-shaped*, as in muscle; or *ciliated*, as already described.

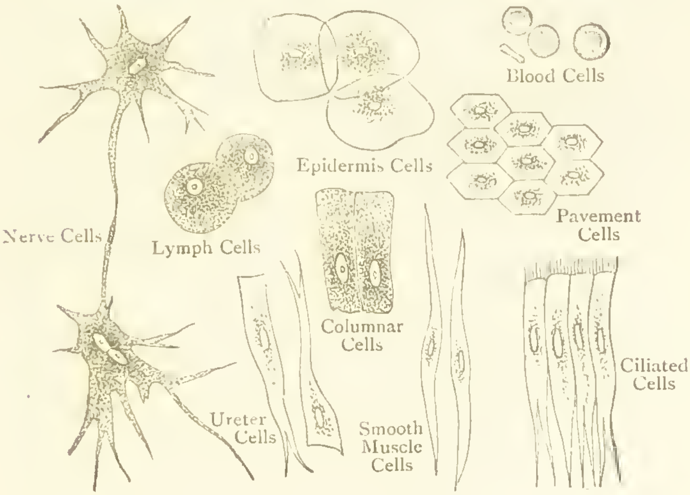


Fig. 13.—Various Body Cells.

Or they may become *fibres*, as in connective tissues; or *tubes*, as in capillaries. (Fig. 13.)

The cells are mostly connected by *intercellular substance*, which was originally produced by their own bodies. This consists of a substance very like protoplasm, only without vital properties, or (as in bone) it may consist of deposits of lime salts, or (as in neuroglia) of fine fibrillar material.

Intercellular Substance.

Or the cells may be in *direct apposition*, and connected by thin walls or processes.

From these simple materials, of which the cells are

the bricks and the intercellular substance is the mortar, the whole of the body is built up.

2. THE TISSUES.

Frey's Classification.

The tissues of the body are classified by Frey as follows :—

A. Tissues composed of simple cells with fluid intercellular substance or matrix.

1. Blood. 2. Lymph and chyle.

B. Tissues composed of simple cells with solid intercellular substance or matrix.

1. Epithelium. 2. Nails.

C. Connective tissues.

1. Cartilage.	4. Connective Tissues (proper).
2. Gelatinous Substances.	5. Bone.
3. Fat.	6. Dentine.

D. Tissues of coherent cells with scanty intercellular substance.

1. Enamel.	3. Muscle.
2. Lens Tissues.	

E. Composite tissues.

1. Nerve.	4. Hair.
2. Gland Tissues.	5. Combined Tissues.
3. Vessels.	

We will, however, now consider the tissues generally under two heads only, namely, epithelial and connective, reserving the consideration of the tissues of the various organs for the chapters devoted to them.

3. EPITHELIAL TISSUE.

Epithelium simple.

Epithelium covers the whole body, and lines every part and cavity of it. As a rule, this tissue is non-vascular. It may be *simple*, that is, in one layer of cells; or *stratified*, in more than one (Fig. 14).

If **simple**, the cells may be *squamous* or pavement, as in the serous and synovial membranes, and in the alveoli of the lungs and lining of the blood-vessels. In the interior of the body this is generally called *endothelium* (Fig. 15).

This serous membrane often contains small openings, round which the cells are cubical. These are called *stomata*, and are for the circulation of the lymph.

Spheroidal simple epithelium is generally secreting, and is found in the liver, kidney, and other glands.

Columnar epithelium lines the stomach and intestines.

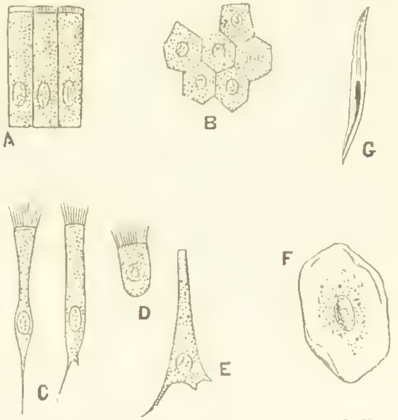


Fig. 14.—Various Kinds of Epithelial Cells.
A, Columnar cells of intestine; B, polyhedral cells of the conjunctiva; C, ciliated conical cells of the trachea; D, ciliated cell of frog's mouth; E, inverted conical cell of trachea; F, squamous cell of the cavity of mouth, seen from its broad surface; G, squamous cell, seen edgeways.

Amongst these cells are frequently found goblet cells, which discharge mucus.

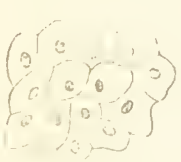


Fig. 15.—Endothelium of the Mesentery of Cat.
The outlines of the endothelial cells, and the nucleus of the latter, are well shown.

Enamel (in the teeth) is a calcified cylindrical epithelium, and consists of hexagonal flattened prisms $\frac{1}{5000}$ inch broad.

Ciliated epithelium has been already described.

Epithelium stratified.

If **stratified**, the epithelial cells are as a rule flattened at the surface, rounded in the middle, and columnar in the deepest layers. A very good example is in the epithelium of the cornea (Fig. 16). This epithelium occurs in the epidermis, in the mucous membrane, and elsewhere. The hair and nails are examples of modified stratified epithelium containing a large

amount of keratin. The ridge-and-furrow or prickle cells occur at times in the median layers, and are like cogged

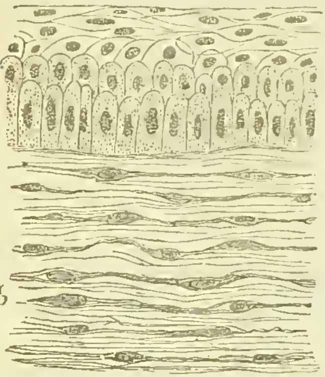


Fig. 16. — From a Vertical Section through the anterior layers of the Cornea.

a, The stratified pavement epithelium ; *b*, the substantia propria, with the corneal corpuscles between its lamellæ.

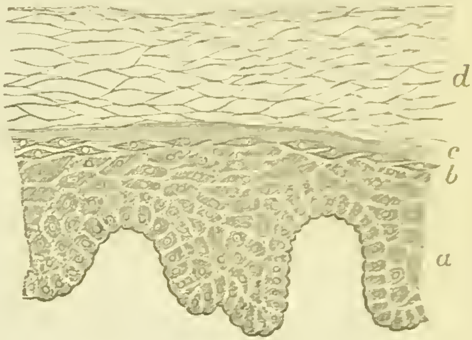


Fig. 17.—From a Vertical Section through the Epidermis.

a, The stratum Malpighii, or columnar cells ; *b*, the stratum granulosum, or prickle cells ; *c*, the stratum lucidum ; *d*, the stratum corneum, or flattened cells.

wheels which fit into each other, but when stretched only touch by the points (Fig. 17).

Sometimes, as in the bladder and ureters, the stratified epithelium is only two or three layers deep ; in other cases it may consist of hundreds of layers.

4. CONNECTIVE TISSUE.

Varieties.

Connective tissue forms the framework or scaffolding of the body, and so pervades every part, that if all the other tissues were removed, we should still have a complete representation of the bodily shape in every part. It is *fibrous*, *cartilaginous*, and *osseous*.

Fibrous.

Fibrous connective tissue, like all others, is made up of cells and intercellular substance. The cells which form the tissue may be branching ; other rounded cells move about in it, called amœboid. Pigment is frequently seen in the branched cells.

The intercellular substance may be fibrillated or homogeneous.

The fibres may be white, forming *white fibrous tissue,*

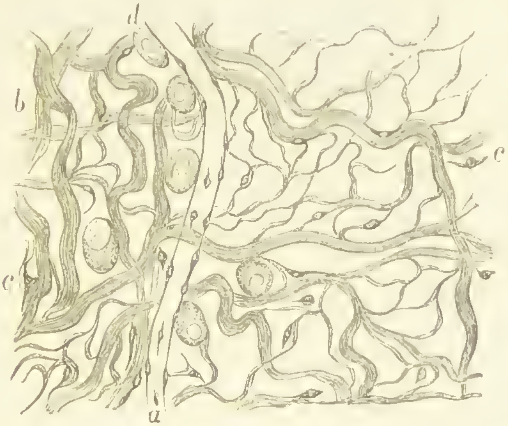


Fig. 18.—Plexus of Bundles of Fibrous Tissue from the Omentum of Rat.
a, A capillary blood-vessel; *b*, bundles of fibrous tissue; *c*, the connective-tissue corpuscles *d*, plasma cells.

and yielding, on boiling, gelatin. This is found in tendons, ligaments, periosteum, and dura mater; in fascia and

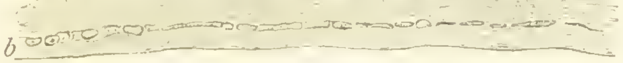


Fig. 19—Tendon of Mouse's Tail.
a, Chains of tendon cells seen broadways; *b*, the same in profile. (E. A. Schafer.)

aponeurosis. It often looks like watered silk, from the wavy direction of the fibres (Figs. 18, 19, 20).

The fibres may be yellow and elastic, forming *yellow elastic tissue*, and yielding, on boiling, elastin. These have a

great tendency to twist, branch, and curl. This tissue is found in the ligamenta nuchæ and subflava, in the spine,

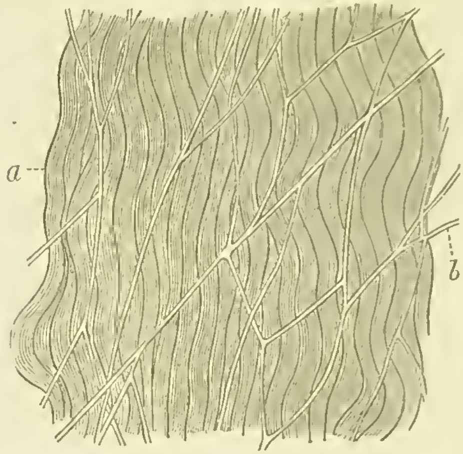


Fig. 20.—From a Preparation of the Mesentery.
a, Bundles of fibrous tissue ; *b*, networks of elastic fibres.

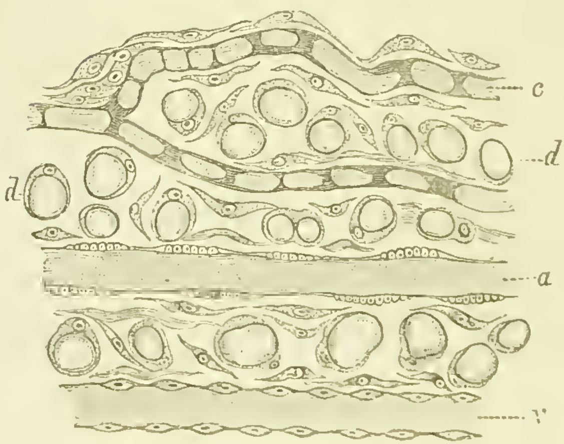


Fig. 21.—From a Preparation of the Omentum of a Guinea-pig.
a, An artery ; *v*, vein ; *c*, young capillary blood-vessel ; *d*, fat cells

in the elastic coat of the uterus, and the tissue of the lungs, in the vocal cords, and in areolar tissue.

Areolar tissue is a soft meshwork of mixed white and yellow fibres, that forms an elastic sheathing for organs, glands, nerves, muscles, etc.

Some special forms of connective tissue remain to be noted. Special Forms.

Adenoid Tissue.—This is found in lymphatic glands, and is formed of finely-branching cells forming an open network, in the meshes of which the lymph corpuscles are packed.

Gelatinous Tissue.—Only found in the adult, in the vitreous humour of the eye, and consisting of a few cells, inclosing mucus in their meshes. It also forms Wharton's jelly in the umbilical cord.

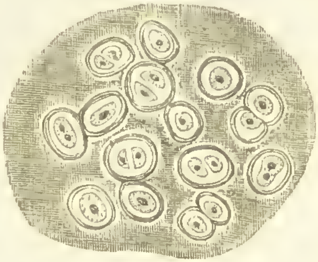


Fig. 22. — Hyaline Cartilage of Human Trachea.
In the hyaline ground substance are seen the cartilage cells enclosed in capsules.

Neuroglia.—This is the groundwork of the nerve centres, and consists of a fine meshwork of fibres.

Adipose Tissue consists of areolar tissue packed with cells containing globules of oil and held in clusters by meshes of capillary blood-vessels (Fig. 21).

The function of connective tissue is mainly mechanical, supporting the various structures where it is found, the yellow elastic serving the purposes of indiarubber. Adipose tissue is a reserve store of "body-warming" food. It is a non-conducting covering to the body beneath the skin, and also to the various internal organs. It is a soft packing material, and, as marrow, serves inside the bones as food, and as a support to the blood-vessels and nerves there. Uses of these Tissues.

Cartilage forms the models of all the bones in the fœtus, and is the precursor of bone. It also supplies a smooth surface in joints, forms tubes, Cartilage.

and a yielding framework when required, as in the front of the chest. It is composed of cells, imbedded in a large amount of intercellular substance, which multiply by fission within the cell-wall or capsule, which eventually forms the intercellular substance. It is generally covered with a membrane called perichondrium. It contains no nerves, and is of the varieties *hyaline*, *white fibrous*, and *yellow elastic cartilage* (Fig. 22).

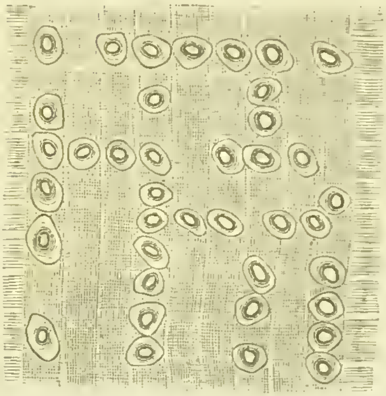


Fig. 23.—Fibro-Cartilage of an Intervertebral Ligament.
Showing the bundles of fibrous tissue and rows of cartilage cells.

Hyaline Cartilage has an inter-cellular substance or matrix like ground glass, which really consists of layers of laminæ like those of an onion round the cells. It contains no blood-vessels, and is principally found in joints and in the costal and nasal cartilages (Fig. 22).

Hyaline.

White Fibrous Cartilage has an intercellular substance or matrix of white fibres arranged in layers. It is found in the semilunar cartilages of the knee-joint, between the vertebra, and in tendons, etc. (Fig. 23).

White Fibrous.

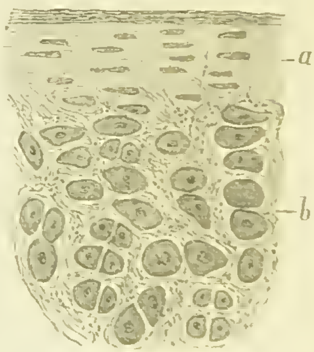


Fig. 24.—From a Section through the Epiglottis.
a, Perichondrium; *b*, networks of elastic fibrils surrounding the cartilage cells.

Yellow Elastic Cartilage has a matrix of yellow elastic fibres, and is found in the external ear, the epiglottis and eustachian tube (Fig. 24).

Yellow Elastic.

Bones (Fig. 25) form the framework of the body, and are hard, tough, and elastic. They are twice as strong as oak; one inch of compact bone will support 5,000 lb. weight. They are a compound of $\frac{2}{3}$ earthy material, principally *phosphate of lime*, and $\frac{1}{3}$ animal, principally *gelatine*. They contain also a little *carbonate* and *fluoride of lime* and *phosphate of magnesium*. These are so intimately blended that all the lime can be dissolved out by weak HCl, and yet leave the bone the same shape but flexible; or the gelatine can be removed by boiling with the same result, only the bone is brittle. The animal matter preponderates in the bones of the young, making them more tough, and the mineral in those of the old, making them more brittle.

Bones.

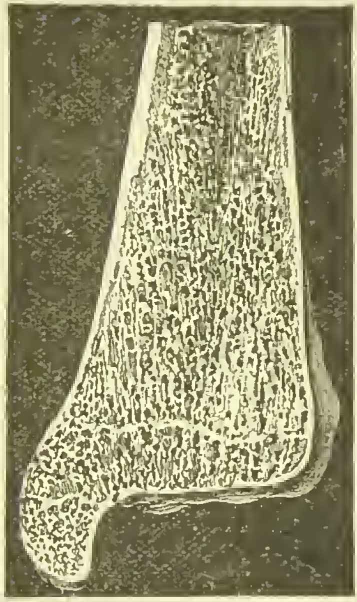
Bone is of different qualities—ivory or *dentine*, *compact tissue*, and *cancellous tissue* or spongy bone. Dentine we get in the teeth, compact bone in the shafts of the long bones, and cancellous tissue in their ends. Cancellous tissue is like pumice stone, only the lattice work is arranged in regular Gothic arches, so as to support the most pressure with the least weight; one cubic inch, weighing a drachm, can support 500 lbs. Flat bones have an exterior of compact tissue and a layer of cancellous inside.

Varieties.

The interior of the bones is filled with marrow, except in the air-cells of the frontal bone and some bones of the face. Red marrow is found in cancellous tissue, and contains large numbers of lymph corpuscles and nucleated blood corpuscles. This marrow is probably one of the sources of the blood corpuscles. Yellow marrow fills the shafts of long bones.

Bones are hollow to make them lighter and stronger. In birds they are filled with warm air, which, in the swift swallow, fills even the small bones of the toes.

Under the microscope bone is found to consist of



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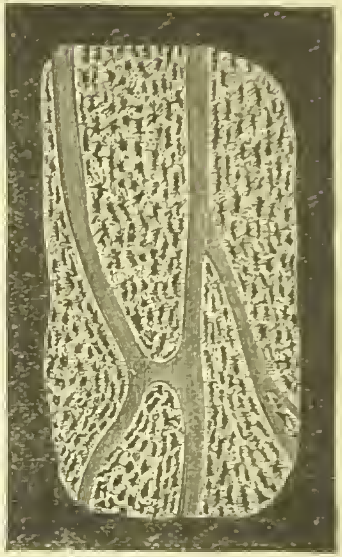
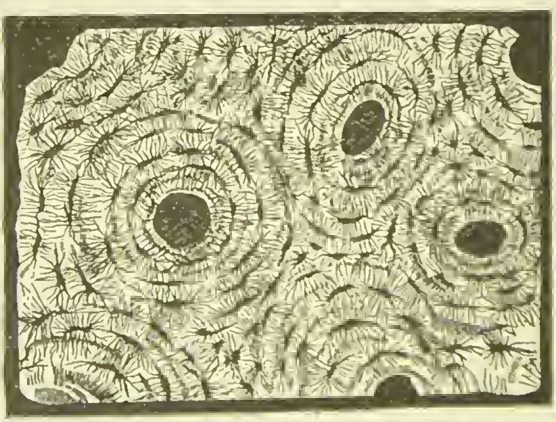


b Longitudinal Section under high power showing Haversian canals.



Transverse Section, showing laminæ, lacunæ, and canals.

Fig. 25.—Sections of Bone.

Structure.

vertical bundles of concentric laminæ with fusiform spaces between called *lacunæ*, connected together by tiny canals called *canaliculi*, $\frac{1}{20000}$ inch in diameter, and surrounding a central duct, called an *Haversian*

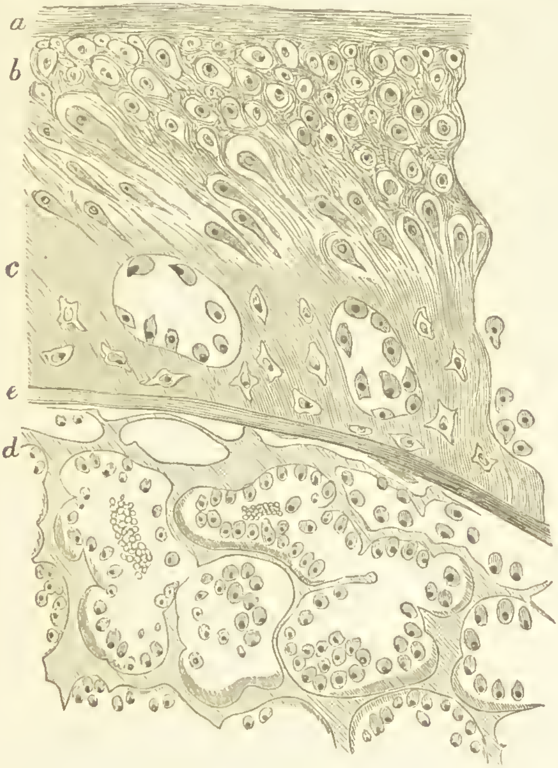


Fig. 26.—From a Transverse Section through the Tibia of Fœtal Kitten.

a, Fibrous layer of the periosteum; *b*, osteogenetic layer of the periosteum; *c*, periosteal bone; *d*, calcified cartilage not covered yet by bone; below this layer the trabeculæ of calcified cartilage covered with plates of bone—shaded darkly in the figure; *e*, boundary between periosteal and endochondral bone.

canal, which branch and are connected with each other. These average $\frac{1}{500}$ inch in diameter, and carry blood-vessels to the substance of the bone, which enter from the surface through small holes. In the lacunæ are large

branched cells called *bone corpuscles*, like the cornea corpuscles in the eye, which nourish the bone surrounding them. Round the bundles of bone lamellæ surrounding each Haversian canal are other lamellæ, binding, as it were, all

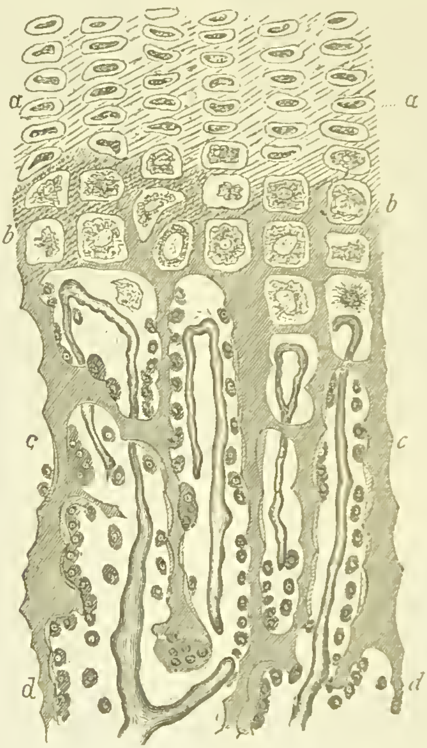


Fig. 27.—From a Longitudinal Section of Femur of Rabbit, through the part in which the intermediary cartilage joins the end of the shaft.

a, Intermediary cartilage; *b*, zone of calcified cartilage; *c*, zone, in which the calcified trabeculæ of cartilage become gradually invested in osseous substance, shaded light in the figure; the spaces between the trabeculæ contain marrow, and the capillary blood-vessels are seen here to end in loops; *d*, in this zone there is more bone formed; the amount becoming greater the farther it is away from this zone.

together into the complete bone. These lamellæ consist of a reticular structure impregnated with lime salts.

Developments of Bone from Membrane.

In the fœtus the bone was originally modelled in *membrane* (in the flat bones) or *cartilage* (in the long bones).

The **membrane**, which afterwards forms the skin covering the bones (*periosteum*), consists of an external fibrous layer and an internal layer of growing cells (*osteo-genetic*). Spiculæ of lime shoot inwards from these growing cells in *osteoblasts*, eventually imbedding them as bone corpuscles in lacunæ. This is formed, at first in an irregular manner (*primitive spongy bone*) and afterwards by the further deposits from the bone corpuscles, into concentric layers of compact bone tissue on the Haversian system.

In **cartilage** the process is involved. The fœtal model of the bone is sheathed in *perichondrium*, which consists, like the membrane, of two layers (Fig. 27) :—

Developments from Cartilage.

1. From the deeper (osteogenetic) layer of cells blood-vessels grow into the cartilage at the spot (centre of ossification) where the bone is to be first found.

2. Next, lime salts are deposited in the matrix of the cartilage.

3. Then, above these lime salts, which form trabeculæ, the cartilage cells arrange themselves in vertical rows and deposit thin bone round the trabeculæ, which are eventually absorbed, thus making spongy bone. This occurs along the centre of the shaft.

4. Meanwhile the osteogenetic layer round the surface is depositing bone salts by means of its osteoblasts, and leaving these imbedded in them as bone cells.

5. This surrounds the spongy bone in the centre, but gradually breaks it down and forms the medullary cavity. The bone is now formed, but it is still spongy in character and irregular.

6. The osteoblasts continue, therefore, by forming concentric layers, to reduce it all into the compact bone with Haversian canals; and thus the process is concluded.

Growth of Bone.

In most bone there are *three* centres of growth, one in the middle and one at each end. These form the shaft or *diaphysis*, and the two ends or two *epiphyses*, and the bone continues to grow in ength at the junction of the diaphysis with the epiphyses, and in breadth by continuous deposits round the shaft from the periosteum.

At various ages between 18 and 25 these various parts of the bone finally unite, and all growth in size ceases. In the long bones there are generally three centres of growth, in the vertebræ as many as eight.

CHAPTER III.

CHEMICAL COMPOSITION AND METABOLISM OF THE BODY.

I. THE PROCESS OF LIFE.

Life is a condition of incessant change dependent on the two opposite principles of repair and decay. *One-twenty-fourth part* of the body (more or less) wastes every day, and this has to be made good. So that we have to take in fresh material at the rate of about *a ton a year.* Life has been happily said to be a condition of dynamic equilibrium; never absolutely so, however, but ever oscillating to one side or the other. We are never the same weight for two minutes together.

Life is Incessant Change.

If a person could be placed upon a scale, accurately balanced with his weight, at 6 a.m., and carry on his day's routine in that position, he would find while lying in bed the scale was very slowly rising, as he got very gradually lighter from the slow wasting of the tissues. When he rose to dress he would find himself ascending in the air more quickly, the destruction of the body being much more rapid with any exertion. At breakfast the scale would suddenly descend to far below its level at 6 a.m. Then till lunch, if in active business with brain or manual work, he would rise steadily At lunch, the process would be repeated, and thus the daily round would go on.

Changes in a Day.

The whole changes that take place in the living body are included in the one word **metabolism**, which not only includes the wear and tear of life, the destruction or **katabolism**, and repair or **anabolism**, of all living tissues, but the processes producing the

Metabolism.

manifestation of living force and energy necessary to its storage and expenditure.

Source of Animal Force.

Animal force and energy are evolved by the reduction of complex substances to simple. A complex substance, such as meat, is built up of a large number of molecules like a tower of bricks. This, of course, has required force or energy to do it. As this substance is reduced to simpler bodies containing fewer molecules, such as urea, carbonic acid, and water, the force stored up in the meat as *potential* energy becomes manifested and used as *kinetic* energy, or active life force.

Twofold Process of Life.

The whole process of life is therefore twofold: the one consisting in the reception, assimilation, metabolism, and excretion of matter, or *the vegetative functions*; the other in the *animal functions*, or the direction of the energy thus set free by means of the will nerves and muscles to the purposes of life.

Food is therefore required for two great purposes. 1. **To repair the tissues of the body.** 2. **To be stored as potential force.**

Balance of Repair and Decay.

It will be evident that during the years of growth (1 to 25) repair is largely in excess of decay; and that therefore large quantities of food are needed for this purpose; that from 25 to 50 all that has to be maintained is the level already reached; while from 50 to 75 decay exceeds repair in a constantly increasing rate, until at death decay alone remains. It is a remarkable fact that our bodies waste and decay more quickly during life than after death.

Suitable Food.

Now with regard to food we have to consider both quality and quantity. It must be *suitable* and it must be *sufficient*. To be suitable for repair it must be of the same nature as that which has to be made good. We will therefore proceed first to examine the composition of the human body.

2. THE CHEMICAL COMPOSITION OF THE BODY.

Seven Leading Elements of the Body.

The human body contains one-fourth of all the known elements (17 out of 67). Chief among them in importance and quantity are the four non-metallic elements—*oxygen*, *carbon*, *hydrogen*, and *nitrogen*, and the three metals *calcium*, *sodium*, and *potassium*.

The following is a rough analysis of the body :—

Oxygen	72·0
Carbon	13·5
Hydrogen	9·0
Nitrogen	2·5
Calcium	1·3
Phosphorus, sulphur	1·2
Sodium, potassium, chlorine, fluorine, iron, magnesium, silicon. Traces only of lead, copper, and aluminium	·5
	100·0

It will thus be seen that the metals form less than 2 per cent. of the whole body.

These substances do not occur often as elements, but chiefly as compounds, which are generally of great complexity. The following are the chief of these :—

INORGANIC.

Four Inorganic Constituents of the Body.

1. **Water.**—This forms two-thirds by weight of the whole body. The fluids of the body contain from 80 to 99 per cent. The solids vary from the enamel with 2 per cent., to the kidneys with 82 per cent. Skin, hair, muscle are all three-fourths water, bone and cartilage one-half, and fat about a quarter.

2. **Gases.**—These include chiefly O, H, N, and CO_2.

O. *Oxygen.*—This gas is essential to all vegetable and animal life. It is the only element directly used in the body—to the extent of 7,000 grains daily.

H. *Hydrogen.*—This gas by its combination in the body with O forms water. It also enters into nearly every organic compound.

N. *Nitrogen.*—This gas is used in its free state merely as a diluent of oxygen, though in combination it is an integral part of every living thing. The daily quantity used in food is 300 grains.

CO_2. *Carbonic dioxide.*—This is formed in the body by the combination of O with carbon. Carbon is also a most important part of organic compounds. 5,000 grains a day are used, and it enters into nearly every article of food.

3. **Salts.**—Chiefly chlorides of sodium and potassium, and phosphates of calcium and sodium. *Sodium chloride* (common salt) is the most important of these. It occurs everywhere, and *is absolutely necessary for existence.*

Calcium phosphate is the most abundant salt, and forms half of the bones.

4. **Free acids.**—Hydrochloric in the gastric juice.

ORGANIC.

Twenty-four Organic Constituents of the Body.

These may be divided into two great classes, nitrogenous and non-nitrogenous. The first consists mainly of albumen, and its derivatives; the latter of carbohydrates (starches and sugar) and fats.

Fifteen Nitrogenous Constituents.

I. NITROGENOUS BODIES.

Seven Albuminous Bodies.

A. **Albumens.**—These all contain C, O, H, N, S. They are all amorphous colloids, insoluble in ether and alcohol, decomposed by acids and alkalies, and heated with nitric acid and ammonia they give orange-red precipitates.

(*a*) *Egg-albumen.*—This is coagulated by heat and with ether, and is hardly soluble in nitric acid. It is found in the white of the egg, and forms the type of the albumen in the body, and the basis of protoplasm.

(*b*) *Serum-albumen* is coagulated by heat and *not* with ether, and is easily soluble with nitric acid. It is found in the blood and lymph.

(*c*) *Acid-albumen* or syntonin is formed from serum-albumen by an acid, and is not coagulable by heat, but is by an acid or alkali. It is largely found in muscle, and is the product of digestion.

(*d*) *Alkali-albumen* is formed from serum-albumen by an alkali, and is not coagulable by heat, but is by an acid or alkali. It is a digestive product. *Casein*, the proteid of milk, is a variety of alkali-albumen containing more nitrogen.

(*e*) *Peptones* are diffusible colloids that give no precipitate with acids or alkalies. They are products of digestion.

(*f*) *Globulins.*—These are albumens, insoluble in water, but soluble in a solution of common salt. They are found in the lens of the eye, in muscle (myosin), in serum (paraglobulin and fibrinogen) and elsewhere.

(*g*) *Fibrin* differs from all other albumen in having a filamentous structure. It is insoluble in water, but soluble in *strong* sodium solution. It coagulates with heat. It is formed in blood after death, probably from the globulins—fibrinogen and paraglobulin.

B. **Albuminoids.**—These all contain C, O, H, N, and mostly S as well. They are, like albumens, amorphous colloids, but differ from them in solubility, and in their reaction to heat, acid, and alkalies.

Six Albuminoid Bodies.

(*a*) *Mucin* is precipatated with acids and alcohol. Is found in mucus.

(*b*) *Chondrin* dissolves in hot water or alkalies. Is found in cartilage.

(*c*) *Gelatin* dissolves in warm water. Is found in bone, skin, etc.

(*d*) *Elastin* is found in yellow elastic tissue.

(*e*) *Keratin* in the horny epidermis, nails, hair, etc. It contains much sulphur.

(*f*) *Hæmoglobin.*—In the blood. This contains iron as well.

C. **Secretions.**

Secretions.

These include the constituents of bile (glycocholic and taurocholic acids), bile pigments, and all the ferments and digestive fluids of the body that contain nitrogen.

Excretions.

D. **Excretions.**—These are the effete products of the body, and include urea, uric acid, leucin, tyrosin, etc.

II. NON-NITROGENOUS BODIES.

Nine Non-nitrogenous Constituents.

These are divided into the two great classes of carbohydrates, and fats and oils.

Four Carbohydrates.

A. **Carbohydrates.**—*These bodies all contain carbon, and hydrogen and oxygen in the proportion to form water.*

(*a*) *Carbohydrates with the formula* $C_6H_{10}O_5$ These include *glycogen*, found in the liver, and *dextrin*, a digestive product of starch, and found in muscle. Starch itself is not found in the body.

(*b*) *Carbohydrate with the formula* $C_{12}H_{22}O_{11}$, having the addition of one molecule of water. This consists of **maltose**, a product of the digestion of starch, like cane sugar.

(*c*) *Carbohydrate with the formula* $C_6H_{12}O_6$, having the addition of two molecules of water. This consists of *glucose*, or grape sugar, found in the liver, blood, muscles, etc.

(*d*) *Inosite*, or muscle sugar, $C_6H_{12}O_6 + 2H_2O$, the

same as grape sugar, with two molecules of water of crystallisation. It occurs in muscles and most other organs.

B. **Fats and Oils.**—These all contain carbon, hydrogen, and oxygen, *but not in the proportion to form water.* They are soluble in ether and chloroform, but not in water.

Four Fats.

Palmitin and *stearin* are two solid fats that form three-fourths of all the body fat.

Olein is a liquid fat that forms the rest. They are all decomposed by alkalies into glycerin and fatty acids.

Cholesterin is a fatty substance found in bile and gall-stones.

Besides this list there are numerous other substances, such as aromatic principles and products of decomposition, that also exist in small quantities.

Aromatic Bodies.

3. GAIN AND LOSS OF THE BODY.

The body loses daily **2½ lbs. of solids and gases, and 6 lbs. of water.**

Income and Expenditure.

The *lungs* contribute 5,000 H_2O, and 15,000 grains CO_2.
The *skin* contributes 11,500 H_2O, and 250 of solids and gases.
The *kidneys* contribute 23,000 H_2O, and 1,100 solids.
The *intestines* contribute 2,000 H_2O, and 800 solids.

The body receives daily nearly **1⅛ lbs.** (8,000 grains) **dry food, 5½ lbs. water** (as liquid or combined with food), and **1⅞ lbs. oxygen gas.**

It will be observed that half a pound less water is taken in than is given out; the balance is made by combustion in the body. Nearly all the nitrogen taken in in 24 hours is excreted as urea.

This daily amount of waste and repair may be regarded as income and expenditure, while the weight of the body represents the capital (Kirkes).

Observe: the body receives a *solid* (food), a *liquid* (water), and a *gas* (oxygen). It excretes *solids* (urea and excreta) by *intestine* and *kidneys*,

a *liquid* (water) by kidneys and skin, and a *gas* (carbonic acid) by the lungs.

Daily Body Work.

The amount of food taken represents about 3,400 *foot-tons* (tons raised one foot high) of force, and of this $\frac{9}{10}$ths, or 3,060 foot-tons (a force equal to lifting a man $8\frac{1}{3}$ miles) are used in maintaining the heat of the body; and the remaining 340 foot-tons in the functions of life, whether in storing force by its physiological processes, or spending it by its nervous or mechanical energy.

Analysis of Expenditure.

We will now consider the chemical analysis of the $8\frac{1}{2}$ lbs. that are lost daily. This amount may be divided into 1 lb. solids, $1\frac{1}{2}$ lbs. gas, and 6 lbs. water. The water and gas need no analysis. The solids contain 4,500 grains of C, 300 grains of N, *or* the general proportion of 15 *parts of C to* 1 *of N.* The amount of hydrogen and oxygen in the solids are of no moment, as they can be supplied by air and water.

If these two elements could, therefore, be used as food, the problem of diet would be solved; but, unfortunately, animals cannot feed on C or N as elements, and we have, therefore, to find that food that will supply the right quantity with the least waste.

4. THE SOURCE OF ANIMAL FOOD.

Vegetable Metabolism.

The vegetable world can obtain its food from inorganic and simple substances. It draws the N from the soil, and the chlorophyll in the leaves causes the water drawn up from the roots to unite with the CO_2 of the air and form starch ($6CO_2 + 5H_2O = C_6H_{10}O_5$). Vegetables build up compound organic forms from simple inorganic, thus storing up force for animals to unbuild and expend, by adding more O (or by combustion), with the formation once more of carbonic acid and water.

Hence the vegetable process is called *anabolic*, and the animal *katabolic metabolism.*

No animals can exist without the vegetable world; for if they prey on one another, the animals they eat owe their existence to vegetables. The vegetable kingdom is therefore an essential link between the inorganic world and the animal kingdom. Animals must have, as food, those compound organic bodies that vegetables spend their lives in making.

Vegetable Life is Essential to Animal.

Just as the vegetable kingdom laid up long ago stores of coal for the work and warmth of nations, by combustion into gas, and water, and ash, so it lays up now stores of starch for the work and warmth of individuals, by slow combustion also into gas, water, and ash.

Animals do not, however, dissipate at once all the energy they get; part is used to build up the still more complex forms of animal proteids; so that when these are eaten (animal diet) they provide a still greater amount of stored-up force.

Proteids also exist in large quantities in cereals and other vegetables, as well as fats.

5. THE VARIETIES OF FOOD.

There are four sorts of food, agreeing with the four great varieties of body tissue: the *mineral*, mainly salts and water; the **nitrogenous** or *proteids;* and the **non-nitrogenous**, or the *carbohydrates* and the *fats*.

The Four Varieties of Food.

Oxygen, though essential to life for purposes of combustion, we do not consider here *strictly* as food, which only includes liquids and solids.

I. MINERALS.

Water is *the most essential* food of the body, and constitutes more than half of it (58·5). No animal organism can live without it. To be dried is to die, as all animal tissues must be largely composed of water, which is continually changed

Water the Most Essential Food.

every day; so that Hoppe-Scyler's saying is true, that "all organisms live in running water."

Salts also Essential.

Salts of various kinds are also essential to life; most tissues being saturated with chloride of sodium (common salt). These are both (however necessary) rather adjuncts to life than supporters of it. There are therefore three great varieties of solid food, from which force or energy is derived.

II. PROTEIDS.

Nitrogenous Food Essential to Life.

Nitrogenous or *proteid* food in some form is absolutely essential to life, for it alone of the three contains N, which is the basis of all living organisms.

Nitrogen is always being lost (the final oxidation of proteids is H_2O, CO_2, and urea (CN_2H_4, a form of ammonia), and an animal without it must waste, and only exists at all by feeding on itself.

Proteids Alone a Wasteful Diet.

It is found in the *gluten* of wheat, in the *albumen* of eggs, in the *casein* of milk, as well as in meat; in the *fibrin* of blood, the *syntonin* of muscle, the *gelatin* of connective tissue, and elsewhere. It is also found in the flesh of all other animals, fish, shell-fish, birds, etc. Proteids (with minerals) can sustain human life alone for a short time; but it is such a wasteful diet that it puts an enormous strain on the digestive organs such as they cannot long sustain. Proteids contain $3\frac{1}{2}$ parts of carbon to 1 of nitrogen, whereas we have seen the daily waste, and therefore the daily food requires to be in the proportion of 15 to 1. To get enough C, therefore, four times as much meat (and N) must be consumed as is necessary; enough N for the daily supply being furnished by 1 lb., whereas it takes 4 lbs. to furnish the C. When we see that instead of 4 lbs. of meat, $\frac{1}{2}$ lb. fat or 1 lb. sugar gives the needed amount of carbon, the advantage of a mixed diet is obvious.

They only contain one-fourth of the Proportion of Carbon.

III. CARBOHYDRATES.

Carbohydrates consist of CHO, the two latter being in the proportion to form water. They are found in starch, sugar, flour, and most vegetables and fruits.

Non-nitrogenous Foods will not alone sustain Life.

Animals fed on carbohydrates only live a very short time, solely by feeding on themselves for the N; as is proved in their excreting less urea than even when starving.

When starving they are of course feeding on the N, but it is more imperfectly assimilated than when other food is taken, hence more urea is excreted.

Dogs fed on sugar and water remain healthy a week, then get ulcers on the eyes (as Hindoos do, who live solely on rice), and die in a month.

The **essential** *food of life is therefore the nitrogenous, the* **accessory** *the non-nitrogenous.*

No animal can use free N (as in the air). It must be combined with COH. And none can live on proteids without minerals (salts and water).

IV. FATS.

Fats or *hydrocarbons* contain also CHO, but the H is in excess of the amount needed to form water. The chief fats are butter, cream, lard, and suet.

Hydro-carbons.

As regards their use in the body, the old division of the four foods into *flesh formers* and *body-warmers* is still of value, though not accurate. Flesh-formers include proteids and minerals (though these also produce heat); body-warmers the starches and oils (though these also nourish the body).

6. DIET.

The best mixed diet to supply 4,500 grs. C and 300 grs. N daily is 2 lbs. of bread and $\frac{3}{4}$ lb. meat; or any food in the proportion of $3\frac{1}{2}$ parts of non-nitrogenous food to 1 part nitrogenous.

Best Mixed Diet.

Of nitrogenous food a baby requires 30 grains per lb. body weight daily (*e.g.*, if 18 lbs., 2,540 grains, or 2 pints milk). This decreases down to 15 grains per lb. body weight in old age (*e.g.*, if 11 stone, 5 oz., or 6 pints of milk).

Food Table. The following analysis of a few leading articles of food will show how far each constitutes a complete diet in itself (Fig. 28).

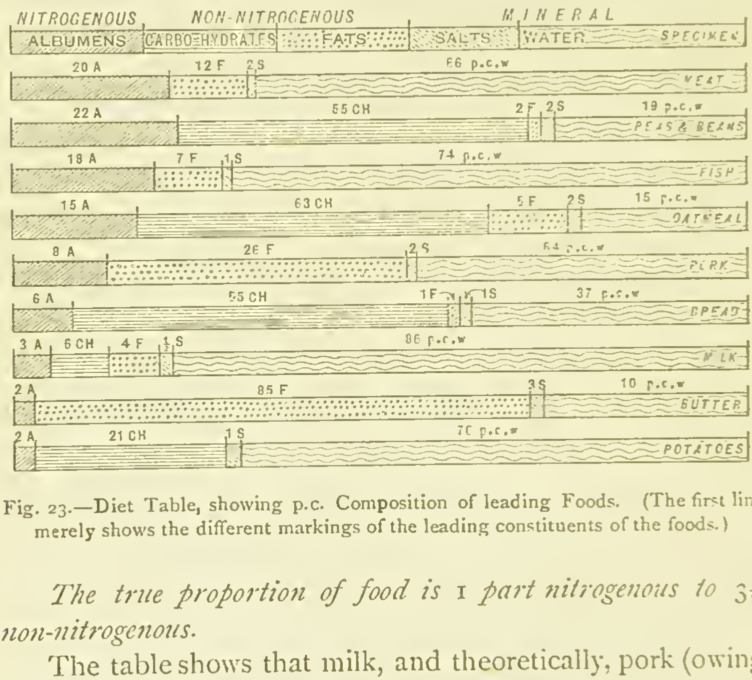


Fig. 23.—Diet Table, showing p.c. Composition of leading Foods. (The first line merely shows the different markings of the leading constituents of the foods.)

The true proportion of food is 1 *part nitrogenous to* $3\frac{1}{2}$ *non-nitrogenous.*

The table shows that milk, and theoretically, pork (owing to the large amount of fat it contains, which, however, renders it very hard to digest, and therefore practically useless as a diet), both contain the right proportions of the two foods.

Milk is 9 parts water, $\frac{1}{4}$ albumen, $\frac{1}{4}$ fat, and $\frac{1}{2}$ sugar; proportions that are perfect for a complete diet.

Bread we see is deficient in N, as are rice and potatoes to a still greater extent, while fish has the proportions reversed, 3 to 1 instead of 1 to 3.

A diet requires, of course, not only to be mixed, but to be varied in quantity according to the amount of work done and waste produced.

It is found that on an average a man requires, in dry solids, three ounces each of proteids and fats, 10 oz. of carbohydrates, 1 of salts, besides three pints of water, or about $\frac{1}{100}$ part of his weight daily. If working very hard, the quantities may be nearly doubled ; if at perfect rest, reduced one-third ; or in quiet life the solids amount to 1 lb., in ordinary work to 22 oz., in hard work to 2 lbs. The amount required also depends on age, season and climate. Such a dietary is fairly represented by $\frac{3}{4}$ lb. each of bread, beefsteak, and potatoes, 2 oz. of butter, nearly a pint of milk, and a quart of water ; or by 1 lb. of meat, $1\frac{1}{4}$ lbs. of bread, $\frac{1}{4}$ lb. butter, and $2\frac{1}{2}$ quarts of water.

Daily Weights of Food Required.

Before 1838 it was believed N could only be obtained from meat, and that vegetables were all non-nitrogenous ; since then it is known that many sorts of grain contain it (as shown in the table) as albumens of different sorts, and hence it is quite *possible* to live on vegetable food only.

Suitability of food largely depends upon its digestibility as well as upon its chemical composition. Thus we have seen that, from one point of view, pork and milk contain about the right proportion of C and N, and yet the one is a most unsuitable article o diet, the other the best we have. As a general rule the N in vegetables is not so easily absorbed as in meat. With regard to the proportion of undigested material in various articles of food, it was found that of meat, eggs, bread, rice, macaroni, the fæces contain of the amount taken, about 5 per cent. ; of milk, peas, and potatoes, nearly 10 per cent. ; of black bread, 15 per cent.

Digestibility of Food.

7. STARVATION.

In starvation we get loss of weight, loss of heat, various symptoms, and death.

Loss of Weight in Starvation.

Death, as a rule, occurs in animals when the body has lost two-fifths of its weight.

The fat nearly disappears, that in the orbit being used up first. The blood loses three-fourths of its weight; the pancreas and liver more than half; the muscles and stomach about two-fifths (40 per cent.); the skin and kidneys one-third; the bones about one-sixth, and the nervous system remains almost unchanged in weight (losing only 2 per cent.).

Loss of Heat.

The heat of the body at first fluctuates four or six degrees, and then shortly before death (probably when the fat stores are exhausted) falls rapidly down to about 30° C. at death. In starvation death is more due to loss of heat than to loss of nutrition. This is to be expected when we remember that nine-tenths of our 3·400 foot-tons of daily food force is used to produce heat. Hence artificial heat will delay death some time.

Other Symptoms and Death.

The symptoms are hunger, thirst, pain, sleeplessness, weakness, and delirium or stupor.

Death generally occurs in a little over a week after the stoppage of all foods, liquid and solid. There is no case known where life has been prolonged for weeks after such stoppage. A very small quantity of food or water only will, however, as we have lately seen in England, prolong life considerably.

8. EXCESS OF FOOD.

Effects of Excess.

Excess of food in the infant is got rid of generally by vomiting, in the adult more generally by the bowels. Before this takes place, however, as much as possible has been digested and absorbed: and the surplus only, that cannot be dealt with, is thus got rid of. The amount absorbed may, however, be greatly in excess of the needs of the body or even of its storage power. We will see how each variety is dealt with.

Minerals.—Excess in salts is not often now met with. Where it occurs intense thirst and skin eruptions of every sort are the result (scurvy, etc.). Excess of fluid is easily dealt with by the kidneys up to a certain extent, but, if

continued, dilutes the blood, impoverishes the tissues, and weakens the digestive organs.

Excess of alcohol at first paralyses various parts of the nervous system, and by irritation of the tissues afterwards causes great overgrowth of the connective tissue, leading to many serious diseases.

Proteids.—The term "luxus consumption," used in various senses in different text-books, is by some intended to mean the direct combination in the blood of an excess of proteids beyond what are needed for building up the tissues; but the term is not of much use, since to a certain extent this combination always takes place. As an excess of nitrogenous diet is very common amongst all who can afford it, it becomes a question of great importance how it is disposed of. If *very* excessive, part may not be digested at all, and be excreted directly. That which is peptonised, if in excess, may be still further changed by the pancreatic juice into leucin and tyrosin, which may pass out as urea by the kidneys. Much that is not so changed becomes uric acid, and lays the foundation for gout, gravel, and stone. That which can be used is stored in the blood as serum albumen.

Effects of Proteid Excess.

Carbohydrates.—These are stored in the liver as glycogen, and the excess is also largely stored in the tissues as fat. Excess can be got rid of by the kidneys as sugar, and gives rise to great dyspepsia.

Effect of Carbohydrate Excess.

Fat.—This is stored to almost any extent in the tissues, and eventually in the muscles and various organs, causing great degeneration of the tissues.

Effect of Fat Excess.

It must not be supposed, however, that the body fat is derived solely from fat food. On the contrary, it was found in fattening a pig that 472 units of fat were stored for every 100 units of fat given. Fat is largely formed from carbohydrates and also from proteids.

CHAPTER IV.

ON DIGESTION.

SECTION I.—THE CARBOHYDRATE OR ORAL DIGESTION.

1. ON DIGESTION GENERALLY.

WE will now consider how the various foods are prepared for assimilation by the tissues. This process is called digestion, and *consists essentially in dissolving all articles of food* so as to be introduced into the blood and thus circulated through the body. No substance can be considered as food unless it is capable of solution by the digestive fluids. Such substances as cork, stones, etc., pass through the body unchanged. The one fact essential to remember is that **digesting means dissolving.**

What Digestion Really is.

The food is introduced into the body and digested in a special tube called **the alimentary canal.** that passes completely through the body *without having at any part any direct communication with the interior.* When any communication does occur, as in disease (typhoid fever, etc.), death ensues. This tube commences at the mouth and terminates at the lower parts of the bowel, and is nearly 30 feet long.

The Alimentary Canal.

The length of this canal is dependent on the food taken. In carnivora it is the shortest, in herbivora it is the longest, and in mixed feeders intermediate.

The canal is subdivided into three parts—the mouth, the stomach, and the intestines. Connected with it are two large digestive glands—the liver and the pancreas.

Three Divisions of the Canal.

As this tube has no direct communication with the body, any food placed inside it is still practically outside the

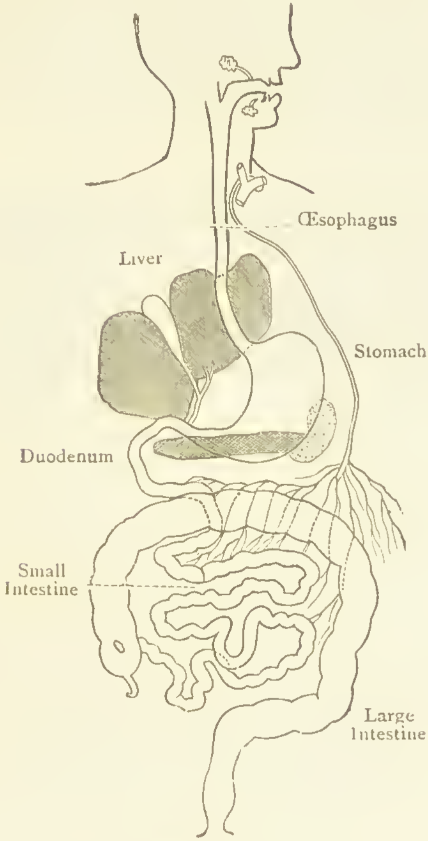


Fig. 29.—Alimentary Canal.

body (just as a train in the Thames Tunnel is not in the river), and the whole purpose of the digestive process is to pass the food inside this tube across the walls, and into the blood-vessels outside. How this is effected we will now consider.

Food Swallowed is Still Outside the Body.

Three Processes of Digestion.

We have already observed that, setting aside minerals and liquid food that require no digestion, being already soluble, we have carbohydrates, proteids, and fats. Observe then that **the mouth or oral digestion is for carbohydrates, the stomach or gastric digestion for proteids, and the intestinal digestion for fats.**

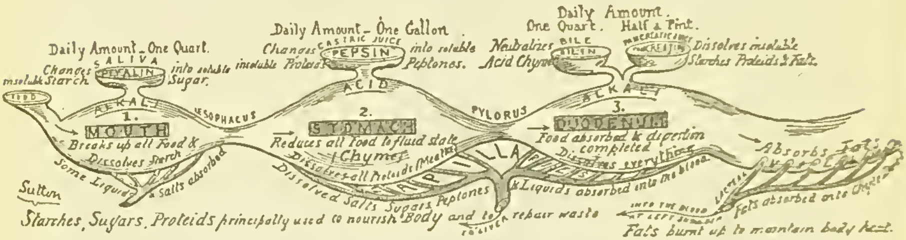


Fig. 30.—Diagram of the Digestive Process.

How the process is effected in each case we will now consider in detail.

2. THE TWO PARTS OF ORAL DIGESTION.

Digestion in the Mouth consists of Two Parts.

The food, whether liquid or solid, all enters the body by the mouth at the rate of about 2 lbs. of solids and two quarts of liquid per diem.

Two changes are effected in the solid food in the mouth. In the *first* place it is ground and cut up into smaller pieces, so as to afford readier access to the digestive fluids, by mastication; and *secondly*, it is mixed throughout with saliva, which has the power of changing starches into sugar.

Cooking.

Cooking is also an important aid to digestion, by rendering the fibres more brittle, and in starchy food by swelling up and bursting the coverings of the starch grains.

PART I.—MASTICATION.

The **teeth,** which are here shown, are 32 in number in the adult and 20 in the child. The approximate date when each tooth appears is marked in *years* on the upper or permanent teeth, and in

Number of Teeth.

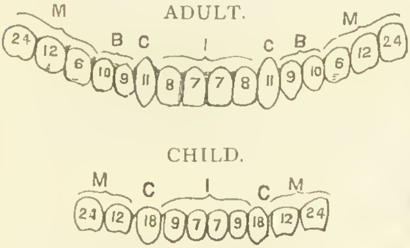


Fig. 31.—The Permanent (above) and Milk Teeth (below).
M, Molars; B, Bicuspids; C, Canine; I, Incisors.

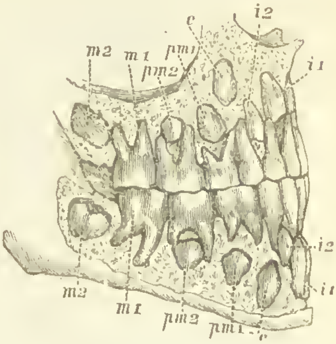


Fig. 32.—View of Milk Teeth, with Germs of Permanent Teeth behind.

months on the lower or milk teeth. As a rule the teeth in the lower jaw are cut before the corresponding teeth in the

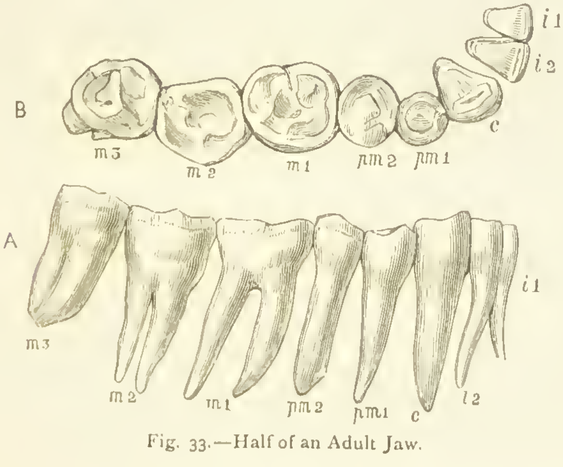


Fig. 33.—Half of an Adult Jaw.

upper jaw. It will be seen from the diagram that the twelve extra teeth in the adult are all molars; room for which is found by the greater size of the jaw. The two bicuspids in the adult take the place of the two molars in the child.

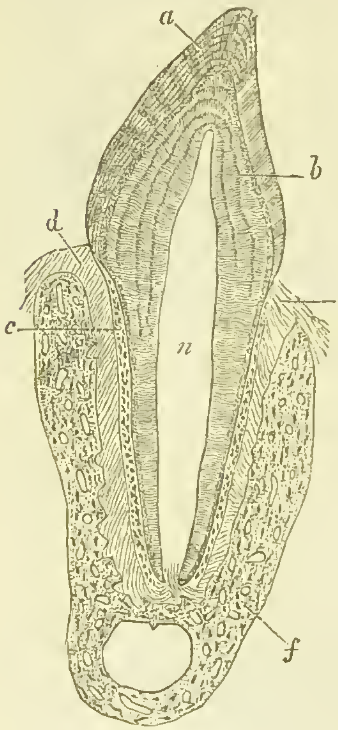


Fig. 34.—Longitudinal Section through the Præmolar Tooth of Cat.

a Enamel; *b*, dentine; *c*, crusta petrosa; *d* and *e*, periosteum; *f*, bone of alveolus; *n*, nerve or pulp cavity. (Waldeyer, in Stricker's Manual.)

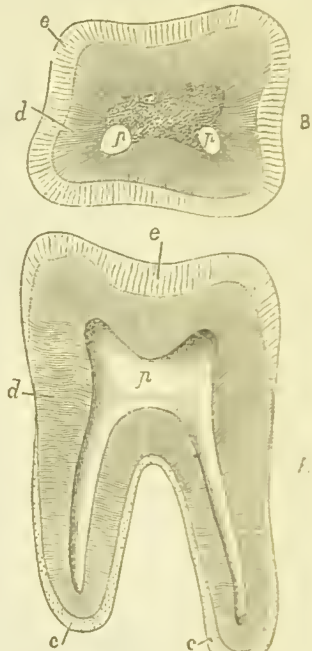


Fig. 35.—Horizontal and Vertical Section of a Bicuspid.

At birth the germs of both the milk teeth and the permanent set are in the head, and at six years of age, when the first molars of the second set have appeared, and before any of the milk teeth are lost, all the teeth, except the wisdom teeth, are in the head, 48 in number.

A tooth consists of the *crown*, or the visible part; the *fang* or fangs, or the part buried in the socket (alveolus) of the jaw; and the *neck* that unites the two. The main part of the tooth, both crown and fang, is made of **dentine** or *ivory*, hollowed in the centre, somewhat in the shape of the tooth, and forming the *pulp cavity* in which are situated the blood-vessels and nerves of the tooth. These enter through a small opening at the end of the root or fang. The dentine is one-fourth animal matter and three-fourths mineral, the one being gelatine, the other mainly phosphate of lime. It contains a number of minute tubules, many of which communicate with the pulp cavity. On the crown the dentine is covered by a cap of a porcelain-like material called **enamel**. It is the hardest substance in the body, and only contains about 2 per cent. of animal matter. It is a calcified columnar epithelium, and is composed of hexagonal rods or fibres, and presents in transverse section, under the microscope, somewhat the appearance of a honeycomb. The enamel is thickest at the top of the tooth, and gets thinner towards the neck. It is itself covered by a horny

Parts of a Tooth.

Dentine.

Enamel.

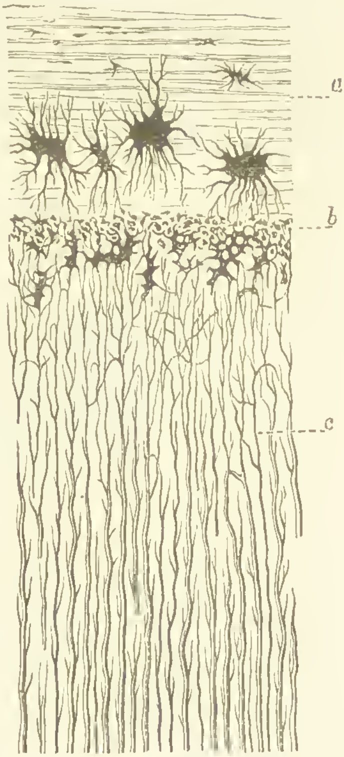


Fig. 36.—From a Section through a Canine Tooth of Man.

a, Crusta petrosa, with large bone corpuscles; *b*, interglobular substance; *c*, dentinal tubules. (Waldeyer, in Stricker's Manual.)

layer, called *Nasmyth's membrane*, which protects the enamel against the action of acids.

Crusta Petrosa.

In the root or fang the dentine is covered with **crusta petrosa**, or common bone; thickest at the end, and, like the enamel, thinning towards the neck.

Development of Teeth.—In the seventh week of fœtal life, the epithelium along the border of the jaw thickens, while a deep ingrowth (of malpighian layer) of epithelium takes place along the median line (primitive dental groove of Goodsir): this is the *common enamel germ.*

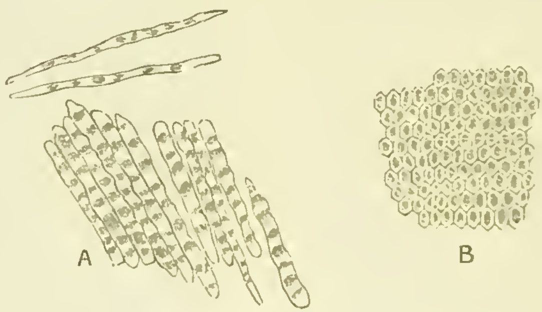


Fig. 37.—Enamel Rods. A, longitudinal; B, in section.

From this, ten deeper ingrowths of epithelium descend into the mesoblast (*special enamel germs*). The bases of these enlarge, then become oval, and at the fourth month a papilla, from the mesoblast beneath, pushes each one up in the centre so as to make the base crescent-shaped, with horns downwards. The epithelium of the germ is columnar and in two layers; between these are developed round thin stellate cells with albuminous fluid. The lower layer grows up and absorbs this, and forms rod-like cells (enamel rods), while the upper layer flattens (squamous) and becomes Nasmyth's membrane. Thus the crown of the tooth is formed of a Turk's cap of enamel externally, and dentine (mesoblast) internally. This contracts to form the cervix, and its surface differentiates into osteoblasts, the interior (pulp cavity) remaining soft. The dentine then lengthens to form the fang. The osteoblasts ($\frac{1}{4500}$ in.) form tubules in dentine round which the pulp calcifies, and into which the processes of the cells extend. The pulp in the cavity is unchanged mesoblast, with vessels, lymphatics, and nerves. As the tooth is pushed

up, the neck is broken off, and left behind to form the germs of permanent teeth, and called *cavities of reserve*. The tooth lies in a dental sac of thickened mesoblast in two layers, vascular and fibrous. The six extra teeth are formed like the others in *posterior cavities of reserve.* The permanent teeth as they grow up absorb all the dentine of the milk set, leaving only the enamel cap to fall off.

Decay of Teeth.

The decay of the teeth is thus easily explained. At the surface of the crown the horny membrane disappears by the grinding of mastication ; and any food lodging and decomposing in the furrows here, or any acids formed in the mouth, can eat through the enamel of the molars till the dentine is reached, when the progress is more rapid. In the same way at the neck of the tooth, if food is allowed to lodge, acids are formed which produce decay easily, the enamel being here so thin. If a hard brush or gritty powder is used to the teeth, the protective membrane is injured, and the tooth rendered still more liable to decay.

Varieties of Teeth.

Teeth are of three principal shapes : the *incisors* or chisel shaped, for cutting the food ; the *canine* or pointed, for tearing ; and the *molars*, for grinding. This variety is evidently intended to deal with a mixed diet. The condyles or the pivots of the lower jaw are also arranged for the same end.

Fig. 38.—Diagram of Condyles, Transverse, Antero-posterior, Circular, and Oblique.

Arrangement of the Condyles.

In the carnivora, where the teeth are mainly for tearing and the jaw only moves up and down, the condyles are as shown—*transverse*. In the rodentia, where the teeth are for cutting, the condyle is *antero-posterior*, allowing of backwards-and-forwards movement of the jaw. In the ruminants, where the teeth are mainly for grinding, the condyle is *circular*, allowing of a rotatory motion ; while in man it is *oblique and partly*

circular, allowing of a combination of all these different motions. The lower jaw has a *double joint*, a pad of fibro-cartilage being interposed for the double object of deadening the sound (the jaw being close by the ear) and of diminishing the risk of dislocation, while allowing of the freest movement. When the jaw is open, the lower teeth are in advance of the upper; when shut, the upper are in advance of the lower.

Nerve Action.

The action of mastication, like so many others in the body, is partly reflex and partly voluntary, the centre for the former acts being (as usual) in the medulla; the latter being, of course, situated in the cortex. The process of mastication consists in a combination of tearing, cutting, and grinding the food into a pulp by means of the teeth, assisted by the tongue and the rotatory movement of the jaw.

PART II.—THE DIGESTION OF STARCH.

The Saliva.

The second part of the process of mouth digestion is that of insalivation of the food, by which means it is all uniformly moistened, which alone enables dry food (such as biscuits) to be eaten at all, and by which the *starchy food is changed into sugar.*

THE SALIVA.

Composition of Saliva.

Saliva is a transparent, watery, slightly viscid, alkaline fluid, with a specific gravity of 1005 and of the following composition:—

Water	99·5
Solids—	
Ptyalin	·1
Proteids (albumen, globulin, mucin)	·2
Salts (principally phosphates and chlorides, with sulpho-cyanate of potassium)	·2
	100·0

Only $\frac{1}{200}$th part is therefore solids, of which half are salts.

It is secreted at the rate of *about a quart a day;* one-third being secreted during and for mastication, and two-thirds at other times.

Mechanically it dissolves any soluble portion of the food, moistens the rest, and by means of the mucin lubricates it and renders it easy of deglutition. Its chief action, however, is chemical, and is due to the minute amount of *ptyalin* it contains.

Action of Saliva.

Ptyalin (discovered in 1831) is one of a large number of bodies known as ferments; which, by their presence alone, and without undergoing any change themselves, enable changes to take place (generally in the form of the addition or subtraction of a molecule of water) in the substance acted upon.

Ptyalin.

Thus Starch $C_6H_{10}O_5 + H_2O$=Sugar $C_6H_{12}O_6$.

Although, therefore, only a trace of ptyalin is found in saliva, it never gets used up or loses its power, but is capable of acting upon any amount of material. It is an unorganised ferment (like the diastase in barley); yeast is an organised ferment. The action of these ferments is generally retarded or prevented by cold, while heat above 140° F. generally destroys them.

The process by which ptyalin converts starch into maltose (sugar) is one of several steps.

Process of Digesting Starch.

Starch grains consist of two parts: a covering of *cellulose* on which ptyalin cannot act, and which does not colour with iodine; and contents of *granulose* or true starch, which colours blue with iodine. *Saliva cannot therefore digest unboiled starch;* hence the great necessity of boiling all starchy foods sufficiently to burst the covering and set the granulose free.

Experiments.

If to a little warm boiled starch iodine be added, a blue colour is obtained.

If to some more a little saliva be added, the starch becomes soon perceptibly thinner and clearer.

Dextrin.

If after a short time a little be tested with iodine, a red colour is obtained, showing the presence of *dextrin*, an intermediate product between starch and sugar.

If it be left longer till the process is complete, and then tested, it gives no colour, being all *maltose*, a sugar nearer to cane than to milk sugar.

Maltose.

Maltose is $C_{12}H_{22}O_{11} + H_2O$; sucrose (cane sugar) $C_{12}H_{22}O_{11}$; glucose (grape sugar) $C_6H_{12}O_6$. That is to say, the molecule of water of crystallisation in maltose is combined in glucose.

But if this digested starch be tested for sugar it is at once found in large quantities.

Tests for Sugar.

Sugar Tests.—The tests for sugar depend on the power it has to reduce *cupric* to *cuprous* salts by throwing down a precipitate of red sub-oxide of copper.

Trommer's test consists in a drop or two of solution of copper sulphate added to the fluid, followed by a table-spoonful or two of a solution of caustic potash. When the mixture is boiled the red sub-oxide of copper is thrown down if there be sugar present.

Fehling's solution, which is a solution of potassic-tartrate of copper, acts in the same way.

If boiled starch be tested in this manner no precipitate is found: but if a little saliva or ptyalin be added first, abundant sugar is soon shown by this test.

The action of saliva is *assisted* by (1) moderate heat, (2) neutral or slightly alkaline medium; (3) removal of the digested product—sugar.

Action of Saliva.

It is *retarded* by (1) cold (and destroyed by high temperature); (2) acids or strong alkalies; (3) presence of much sugar.

Observe here that the mouth digestion is *neutral*, the stomach digestion *acid*, and the intestinal digestion (pancreatic) *alkaline*.

Saliva has *no action* on proteids or fats, or on sugar, gum, etc. The saliva has no digestive power before the sixth month, hence flour foods cannot then be digested.

THE SALIVARY GLANDS.

The saliva is formed in three pairs of glands.

The Parotid Glands.

One pair, the parotid glands, are situated in the cheeks, and open into the mouth by a small duct (Steno's) at the back of the second molar tooth on each side. These glands secrete a clear limpid saliva free from mucin.

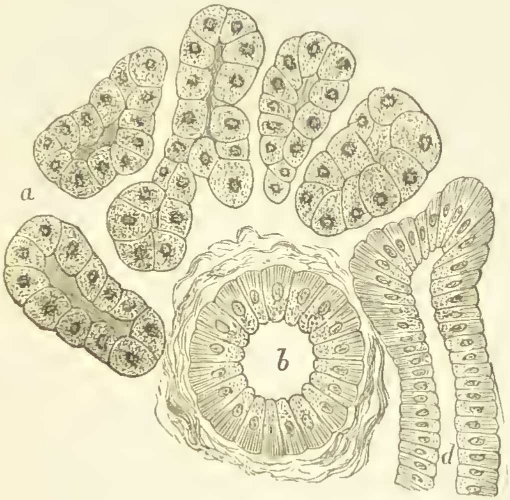


Fig. 39.—From a Section through a Serous or True Salivary Gland; part of the Human Submaxillary.

a, The gland alveoli, lined with the albuminous "salivary cells;" *b*, intralobular duct cut transversely.

Sublingual and Submaxillary Glands.

The other two pairs are the sublingual and the submaxillary. The former are beneath the tongue, and the latter are further back in the floor of the mouth, and open with the former by common ducts (Wharton's). The saliva from these is more viscid, and contains much mucin.

In animals this is sometimes of great value, as in the great anteater, which has enormous submaxillary glands (the parotid remaining the same size), for lubricating its long tongue with the viscid secretion by which it catches its food.

The *parotid secretion* is most watery, and has less digestive power, and is principally for diluting and mixing.

The *submaxillary secretion* is most active in digestion of starch.

The *sublingual secretion* is most viscid, and is for coating and lubricating the food.

Fig. 40.—From a Section through the Orbital (mucous) Gland of Dog. Quiescent state.

The alveoli are lined with transparent "mucous cells," and outside these are the demilunes of Heidenhain. (Heidenhain.)

Besides these three pairs there are many smaller glands in the mouth called *buccal*, that also secrete fluid.

The salivary are *compound racemose* (or grape-like) glands.

Structure of Glands.

The duct divides and subdivides till the small branches end in bunches of rounded spaces ($\frac{1}{500}$ inch in diameter), like grapes, lined with cells regularly arranged like the spokes of a wheel around the space in the centre.

In true salivary glands, as in the parotid, all these cells are granular. During secretion the cells get gradually

clearer at the outer edges, the granular contents being less, and concentrated near the centre.

In mixed salivary and mucin glands, as in the submaxillary, the mucus cells are bright and clear, and there are in addition dark semilunar cells round the edges.

It seems probable that during activity the mucus cell breaks up and one of the semilunar marginal cells takes its place.

Fig. 41.—Acini of Serous Gland.
A, At rest; B, first stage of secretion; C, prolonged secretion. (Langley.)

The saliva is not a transudation from the blood, but a true secretion. It is continued after the head is cut off; it is 1 *or* 2 *degrees hotter than the blood*, showing chemical action; and is not dependent in quantity solely on the supply of blood. It is secreted by reflex nervous influence.

Saliva a true Secretion.

Irritation of the *chorda tympani* (a branch of the facial nerve) produces copious watery saliva and an increased supply of blood.

Nerve Action.

It probably contains two sets of fibres, one to the blood-vessels, the other to the gland cells. If one of these sets be paralysed by atropine (belladonna always makes a dry mouth, and atropine is the alkaloid), there is a supply of blood but no saliva.

Irritation of the sympathetic produces a flow of viscid

saliva (though it stops the blood supply by chemical action of the cells) and discharge of mucin. This diagram easily explains the reflex action. If both nerve supplies be cut off, as in paralysis, the saliva is secreted copiously and

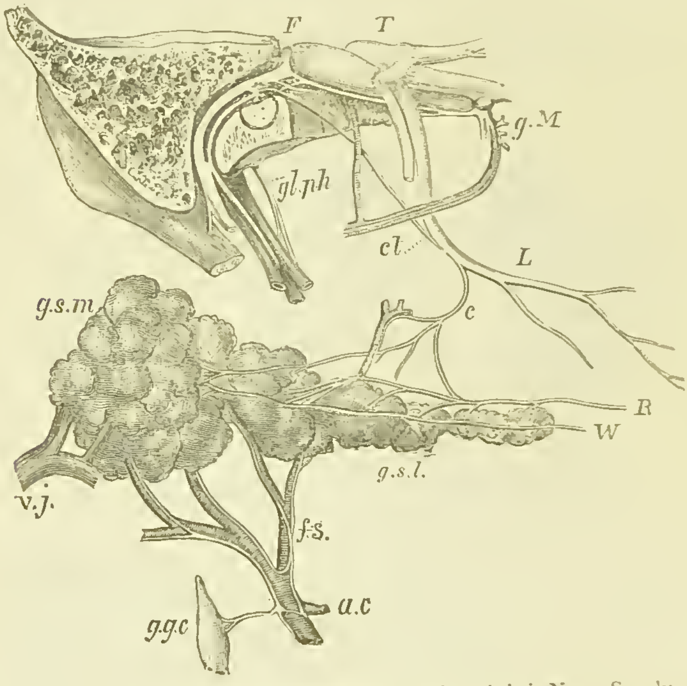


Fig. 42.—Submaxillary and Sublingual Glands and their Nerve Supply.

F, Facial nerve; *T*, Gasserian ganglion; *gM*, Meckel's ganglion; *gl ph*, Glosso-pharyngeal nerve; *cl*, chorda tympani; *L*, Lingual nerve; *c*, continuation of chorda tympani; *gsm*, Submaxillary gland; *W*, Wharton's duct; *gsl*, sublingual gland; *R*, duct of sublingual gland; *vj*, jugular vein; *ac*, carotid artery; *ggc*, superior cervical ganglion; *fs*, sympathetic filament.

continuously (paralytic secretion), as is seen in paralytics, who frequently dribble like infants. It is excited by any stimulus in the mouth, by the scent or thought of food, and by other actions, such as vomiting or mastication.

Causes that influence Secretion.

The flow is checked by nervous influences, such as terror.

The ordeal of rice, practised on suspected murderers in India, is based on this fact. If the man can swallow the dry rice (which is very possible by the aid of saliva), he is pronounced innocent ; if he cannot (the flow of saliva being checked by fear), he is pronounced guilty.

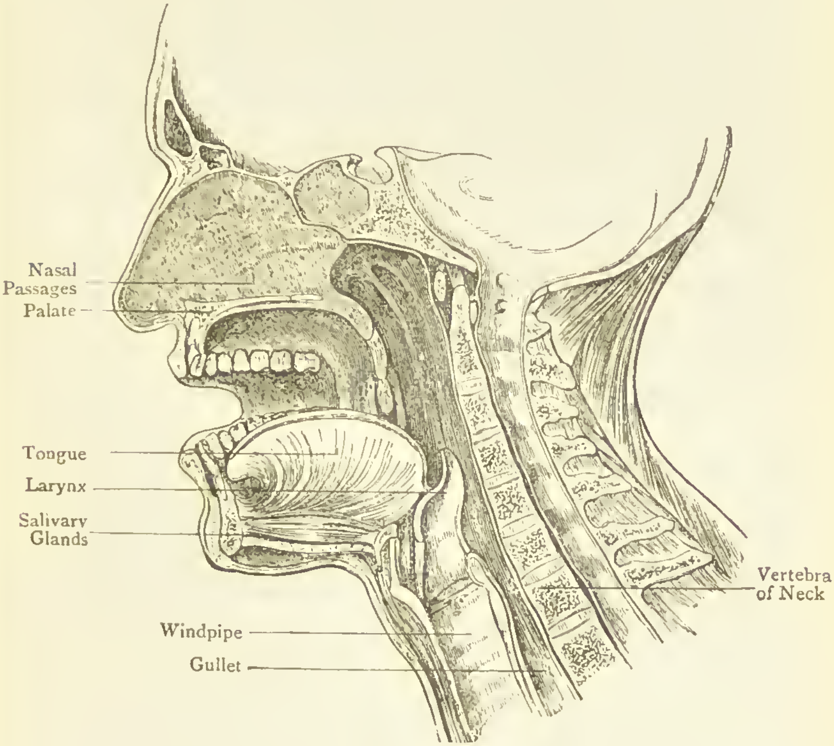


Fig. 43.—Section of Mouth, Nose, Throat, and Larynx.

It is also inhibited by certain drugs, such as tannic acid; and is excited by other drugs, such as pellitory root.

Hence, sipping tea at meals checks the digestive process here, and also in the stomach.

The flow of the parotid gland (from its position) is specially influenced by the act of mastication.

3. THE PHARYNX.

The Pharynx.

The throat or *pharynx* is divided from the mouth proper by the two *tonsils* at the sides and the *soft palate* above, that hangs down like a curtain with a prolongation called the *uvula* in the middle.

The Tonsils.

The **tonsils** are masses of lymphatic tissue like Peyer's patches in the intestine. They contain numerous crypts (some ten or twelve in each), at the bottom of which glands open that secrete a tenacious mucus, which coats the bolus of food as it passes between them.

The researches of Metschnikoff and others lead us to think that they, in common with Peyer's patches in the intestine, may be the seat of active combats between invading bacteria and the defending leucocytes.

The Seven Openings into the Pharynx.

The **pharynx** is a narrow, lofty (as compared with the mouth) chamber containing **seven openings.** In front above are *the two nares ;* and below, *the mouth ;* at the sides, *the two Eustachian tubes* leading to the ears; and in the floor in front, the *larynx* and windpipe ; and behind, the *œsophagus* or gullet.

The whole upper part of the pharynx is lined with columnar ciliated epithelium.

4. THE ŒSOPHAGUS.

The Œsophagus.

The **œsophagus** or gullet is the narrowest and strongest part of the alimentary canal. It is a tube nine inches long, reaching from the throat to the stomach. It consists (in common with nearly all the tubes of the body) of four coats, an outer fibrous one, a middle muscular one, a submucous coat, and an inner mucous membrane.

The Four Coats.

The *fibrous* coat is loose and imperfect. The *muscular* coat is in two layers, the outer longitudinal,

the inner circular. *Between the two coats here and throughout the tube is a plexus of nerves* (**Auerbach's**), that everywhere is believed to govern the peristaltic movement of the muscles. The submucous coat consists of connective tissue and numerous glands. It is divided from the inner coat by a band of longitudinal muscle fibres called the *mucous muscular layer*, and *by a second plexus of nerves which also runs through the intestine* (**Meissner's**), and is supposed to govern the processes of secretion and absorption. The muscles, except just in the upper part, are all unstriped, and are involuntary. The inner coat, or *mucous membrane*, consists of fibrous tissue lined with several layers of squamous epithelium, which is thrown into longitudinal folds when not in use. The numerous mucous glands which exist in the submucous coat open on the surface of the mucous membrane.

5. DEGLUTITION.

Deglutition.

Deglutition has been generally divided into three acts: 1, carrying the food to the back of the mouth; 2, across the pharynx; 3, down the gullet. The first of these acts is voluntary, the other two are not. The whole passage of the food from the mouth to the stomach takes six seconds.

First Act.

The food, formed into a long oval *bolus*, is carried to the back of the tongue, the lips are closed, and the tongue is pushed back and arched so as to close the entrance to the mouth.

At the same time the soft palate is raised horizontally backwards, and, meeting the sides of the pharynx, completely prevents any passage of the food upwards into the walls or Eustachian tubes.

When the soft palate is deficient the food often passes upwards into the nose.

Five of the openings are thus closed, and the *first act* is completed.

To carry the food across from the tongue to the gullet, the opening of the larynx between must be completely closed, not only to solids but liquids. This is

Second Act.

effected in a threefold manner:—1st, the movement of the tongue backward closes the epiglottis tightly down over the mouth of the larynx; 2nd, the vocal cords contract and fit closely together below; 3rd, the whole larynx is drawn upward and forward by muscles, under cover of the back of the tongue. The food thus passes downwards on the sloping floor formed by the epiglottis into the gullet behind, and this completes the *second act.*

The passage of the food, liquid or solid, down the gullet is *never by gravity*, but is always a muscular act, excited by the food stretching the tube. The

Third Act.

peculiar motion of smooth muscle fibre is called *peristaltic*, and is in a succession of waves, spreading from above downwards; thus gradually pushing the food either downhill or, as in horses drinking, uphill into the stomach. This completes the *third act* of deglutition and the first great section of the digestive process.

CHAPTER V

SECTION II.—THE PROTEID OR GASTRIC DIGESTION.

I. THE STOMACH.

The Stomach described.

THE **stomach** is a bag about ten inches long, four broad, and four deep—but varying greatly in size according to the food it contains—lying transversely across the body from left to right, behind and below the end of the sternum. It is separated from the lungs and heart in the thorax above by the

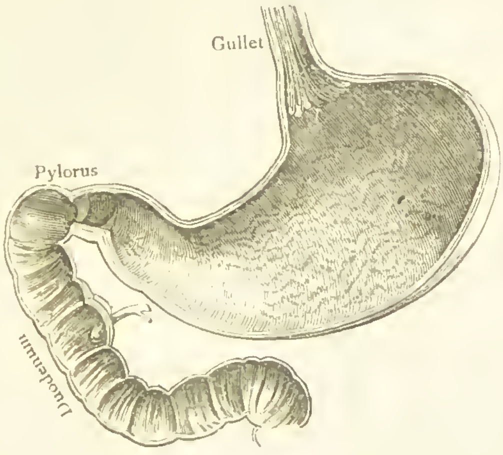


Fig. 41.—The Stomach and Duodenum.

diaphragm; but the heart especially may, when it is distended, be almost said to rest upon it.

The general shape of the human stomach is similar to the "bag"

in the bagpipes, which is formed from that of a cow. The proximity of the heart to the stomach explains the phenomena of palpitation in cases of stomach distension, and is well illustrated by the case of a man who died from a thorn he had swallowed into his stomach penetrating into the heart.

The Heart and Stomach.

The stomach is simply a distension of the general intestinal canal for a special purpose.

Stomach a part of Alimentary Canal.

Ruminants have altogether four stomachs for the long process of digesting raw vegetable food. Birds, being destitute of teeth, have stomachs with surfaces so hard that they grind the food there, instead of in the mouth. These are called *gizzards*.

The gullet enters at the upper surface of the stomach, about three inches from the left or cardiac end. The opening into the bowel called the *pylorus* is at the extreme right end. The lower sweep from the gullet round to the pylorus is called the *greater curvature*, while the upper sweep above is called the *lesser curvature*.

Openings into the Stomach.

Like all other parts of the digestive canal, the stomach has four coats. The *outer* one in this case is formed of a fine *serous* membrane, that everywhere invests the organ of the abdomen called the *peritoneum*. The *second* coat is muscular, and consists of different layers arranged in at least three ways, between which we find *Auerbach's plexus of nerves*. The outer layers are longitudinal. The circular are next, and are thickest at the pyloric end; while the oblique (which are a continuation of the circular fibres of the gullet) principally encircle the cardiac end, and form a sort of sphincter round the opening of the œsophagus. The *third* is the submucous coat of loose connective tissues. Then we get the mucous muscular layer, consisting here of both circular and longitudinal fibres, with the *second nerve plexus* (*Meissner's*); and, *lastly*, the mucous membrane, which is of

The Walls of the Stomach.

considerable thickness, and, like the œsophagus, when not distended is thrown into numerous longitudinal *rugæ* or folds.

The mucous membrane is lined with a single layer of

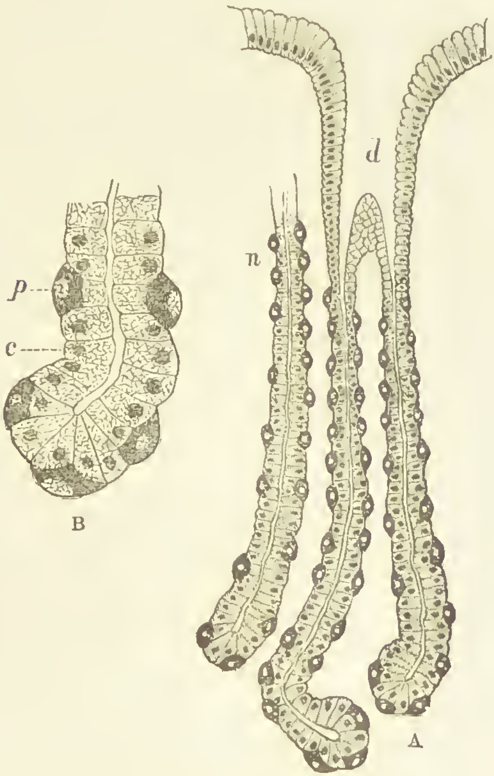


Fig. 45.—Peptic Glands from the Cardiac End of the Stomach.
A, Under a low power; *d*, duct; *n*, neck; B, part of the fundus of a gland tube under a high power; *p*, parietal cells; *c*, chief cells.

columnar cells that secrete mucus, and which form a marked contrast to the flat squamous cells of the gullet. It is closely covered everywhere with pits or *alveoli* leading to glands.

The Mucous Membrane.

2. THE GLANDS OF THE STOMACH.

These pits and glands are of two varieties.

Those at the pyloric or right end of the stomach have long, broad alveoli, with short branched glands at the bottom, two or three opening into one alveolus or pit. They are lined with a single layer of finely granular cells, the alveolus being lined with the single columnar layer of the stomach.

The Pyloric Glands.

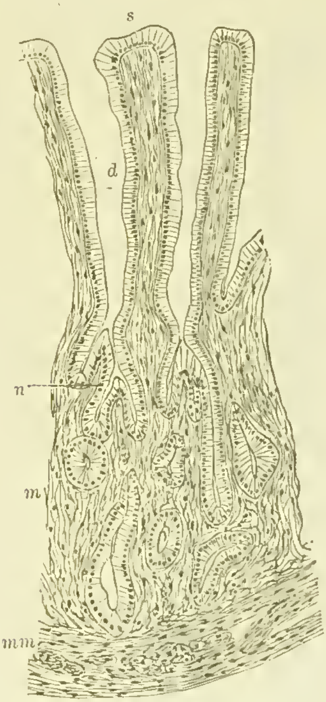


Fig. 46.—From a Vertical Section through the Mucous Membrane at the Pyloric End of the Stomach.

s, Free surface; *d*, ducts of pyloric glands; *n*, neck of same; *m*, the gland alveoli; *mm*, muscularis mucosæ.

The Cardiac Glands.

The alveoli at the cardiac or left end are much shorter and smaller, and are lined with columnar epithelium.

Into their bases open one or two fine tubular glands about $\frac{1}{300}$ inch in diameter and from $\frac{1}{20}$ to $\frac{1}{60}$ inch in length. They have very constricted orifices, and are lined by two kinds of cells. The *central* cells are small, columnar and granular.

The *parietal* cells bulge out the walls of the tubular, and are large, oval, darkly granulated cells, with large bright nucleus.

Action of Pyloric Glands.

The pyloric are also called mucous glands; their chief work being to secrete mucin or mucus from the cells that line the deep alveolus. They also secrete a small amount of pepsin from the gland itself.

When one of these cells either here or elsewhere in the alimentary canal has discharged its contents, it shrivels up at the base and assumes a goblet shape, hence such cells are called goblet cells.

The cardiac glands are called peptic because their chief work is to make *pepsin*, which is done by the *central* cells, while the *parietal* layers have the power of forming *hydrochloric acid* from the salt ($NaCl_2$) in the blood. After prolonged work the cells become clearer from without inwards, like the cells of the salivary glands.

Action of the Cardiac Glands.

3. THE GASTRIC JUICE.

Digestion in the stomach, as in the mouth, consists of **two processes**: the one, *solution of the proteid* or meat foods by the digestive fluids; the other, the *constant movement of the food*, which corresponds to mastication.

Two Processes in the Stomach.

The **gastric juice** is the digestive fluid of the stomach, and is produced by the glands we have already considered, at the rate of about 2 gallons daily. It is a clear colourless fluid of sour taste and odour, with a sp. gr. of 1001. It has the following composition.

Composition of Gastric Juice.

Water	99·3
Pepsin	·3
HCl (free)	·2
Salts, Chloride and phosph.	·2
	100·0

The amount of HCl may be reduced to only one-tenth of this quantity.

The human gastric juice has been obtained pure during life by Dr. Beaumont from a man named St. Martin, through a fistula caused by a gunshot wound in the stomach; and by Schmidt from a woman who also had a fistula. The mucous membrane was induced to act by the introduction of a few hard peas, and the fluid drawn off pure through a tube.

How it has been obtained.

Function of the Gastric Juice.

The chief function of the gastric juice is to convert **insoluble proteids, which at first coagulate, into soluble peptones,** that can pass easily across the wall of the canal. It is essentially an acid digestive, and cannot act in a neutral or alkaline medium. It acts like saliva, by means of a ferment called pepsin. The action on proteids is in at least two steps.

Process Detailed.

If a little hydrochloric acid be added to a little diluted white of egg at about blood heat, acid albumen or syntonin is formed, which is all precipitable by boiling and neutralising.

Parapeptone.

If, however, gastric juice be added to warm white of egg solution, or pepsin to the acid mixture, it is found after a time that only a part is precipitated by boiling; the rest is the fluid peptone. Part of the precipitated albumen is syntonin, and the rest is a substance like it, called *parapeptone.*

These parapeptones are also called albumoses. They are never found in the body save in disease. Injected into the blood they are active poisons. In health they are probably absorbed and destroyed in the liver. Their presence in disease *may be* one cause of fever.

Peptone.

Peptone is albumen dissolved by adding to it a molecule of water (like starch), by the power of the ferment.

It is characterised by—

1. Not coagulating with heat.
2. By being precipitated with tannic acid.
3. By diffusing freely across animal membrane.
4. By not being precipitated by nitric acid.
5. By giving a pink reaction with cupric sulphate and caustic potash, the "peptone or biuret" reaction.

The ferment is not destroyed by its action, but it is destroyed by boiling.

Its action is aided by—

Conditions that influence the Ferment Action.

1. Blood heat.
2. An acid medium, and hydrochloric acid is best.
3. The removal of the peptones as digested.
4. Fine subdivision of the proteids.

It is retarded by contrary conditions.

After use the gastric juice is absorbed.

Gastric juice also contains a milk-curdling ferment (rennet), most abundant in infants. One part of rennet can precipitate 800,000 of casein.

4. OSMOSIS, COLLOIDS AND CRYSTALLOIDS.

Before leaving this part of digestion we will consider in what way peptones are enabled thus to pass across animal membrane.

Filtration and Osmosis.

Filtration is when a fluid passes out (through a membrane) under pressure.

Osmosis is when two fluids, one on either side of a membrane, interchange; one passing in, the other out. This can only take place between fluids that will mix, like wine and water. It cannot take place between oil and water.

Positive and Negative Osmosis.

If more fluid passes in than out, as when an alkali solution is inside and water out, it is called *positive osmosis*; but if more passes out than in, as when an acid solution is inside and water out, it is called *negative osmosis.*

Colloids Described.

Colloids are gum-like bodies that will not crystallise, with large molecules. They will not transude through membranes, or only very slowly. They include all starches and all proteids. **Peptones are the only colloids that transude freely.**

Crystalloids Described.

Crystalloids are bodies that crystallise easily and transude readily, and include all sugars and salts. **Hæmoglobin is the principal crystalloid substance that will not transude.**

Circulation in Digestion.

In digestion a sort of circulation is kept up between the blood and the food. Positive osmosis sets in first, and the digestive fluids and mucus are poured into the canal; then, as the food becomes crystalloid or capable of ready transudation, negative osmosis sets in, and the digested products pass rapidly into the blood.

Reconversion into Albumen.

After absorption the peptones are believed to be reconverted into albumen (probably serum albumen), or else they would speedily diffuse out of the blood-vessels again.

Curdling Ferments in Gastric Juice.

Besides pepsin, the gastric juice contains a special ferment for the curdling of milk (very abundant in calves and called *rennet*). Gastric juice has no action on starch; it slowly changes cane (sucrose) into grape sugar (glucose), probably by the mucus it contains; it dissolves the albuminous coverings of fat, and thus forms it into oil. It is strongly antiseptic.

Closer investigations show that what the glands actually secrete is a substance that forms pepsin when mixed with hydrochloric acid, called pepsinogen. It is also found that the peptones produced are of two varieties: one called *antipeptone*, which is unchanged afterwards by the pancreatic juice; the other called *hemipeptone*, which is split up into leucin and tyrosin. It is also found that a poisonous alkaloid is formed in the peptones as an ordinary product of gastric digestion.

5. PROCESS OF GASTRIC DIGESTION.

The Second Part of Digestion.

We will now consider the second part of digestion—that is, by movement—and in so doing will review the whole process.

Before the food comes into the stomach, from its presence in the mouth, or even from its smell and anticipation, the empty stomach, pale and nearly dry, is affected by the reflex action of the *sympathetic* and *pneumogastric* nerves, and begins to blush rosy red, or the capillaries become distended with blood. Very soon drops begin to ooze out from the honeycombed surface all over, and before long a little pool of clear gastric juice is collected. The softened food, thoroughly mixed throughout with saliva (the action of which still continues to some extent in the stomach), enters at the cardiac end, and immediately the movement of the stomach begins, while more gastric juice is poured forth. The cardiac entrance is tightly closed, as well as the pyloric valve, and the muscular walls contract on the contents, and a peristaltic or spiral wave of motion begins, getting more rapid as digestion goes on. The effect of this is to propel the food rapidly from left to right along the side, while it returns in a current along the middle.

Flow of Gastric Juice.

Entrance of the Food.

Stomach Movements.

Every part of the food is thus thoroughly exposed to the action of the gastric juice.

Value of these Movements.

The value of this part of the digestive process is seen by experiment. A piece of boiled salt beef took *ten* hours digesting artificially with gastric juice; part of the same piece only took *two* inside the stomach.

The length of the digestive process varies with the food taken. It averages four hours. Easily digested articles, such as tripe, take one hour; pork takes five or six.

Time for Gastric Digestion.

The semifluid contents of the stomach during digestion become more and more *acid*, and it is believed this relaxes the pyloric valve, hitherto tightly closed, so that at first the non-liquid parts and the whole contents of the stomach pass through into the

Opening of the Pyloric Valve.

duodenum, and the second great section of the digestive process is completed.

6. SELF-DIGESTION OF THE STOMACH.

Why the Stomach does not Digest itself.

One question of interest is why the stomach does not digest itself, seeing its walls are formed of proteids. The best answer that has been given is based on the circulation of the blood in its walls.

Alkalinity of the Blood.

The blood first of all supplies the digestive glands, then takes from it HCl, leaving the soda in the blood, which is thus abnormally alkaline as it passes into the surface capillaries of the mucous membrane, and it is believed that this alkalinity of the blood circulation acts as a special protection against the digestive power of the gastric juice.

After sudden death, if the stomach contains gastric juice at the time, the stomach is frequently found partly or wholly digested, and sometimes parts of the neighbouring organs as well. The principal objection to the foregoing theory is that the pancreatic juice that acts on proteids also is intensely alkaline; the walls of the intestines have thus no protection against this fluid from the blood, and yet they are not digested. The old theory of the vital power of living cells to resist destruction still remains as an alternative.

Abnormal Stomach Contents.

The abnormal contents of the stomach are sometimes very remarkable, as showing what it can receive without apparent injury. In the stomach of a lunatic after death was found a mass weighing 2½ lbs., consisting of thirty-one entire spoon-handles, each five inches long, four half-handles, nine nails, half an iron shoe-heel, a screw, a button, and four pebbles (Treves).

Amongst the objects that have passed through the pylorus and the entire intestines without doing injury are a metal pencil-case 4½ inches long, ten ounces of garden nails, fragments of crockery-ware, a fork, a door-key, and a set of artificial teeth. Needles and other sharp substances swallowed travel through the walls and appear under the skin in various parts—one (reported in the *Lancet*) in the middle of the thigh.

7. VOMITING.

The action of **vomiting** very much resembles, in its first movements, that of whooping-cough. A deep inspiration is first taken. The *glottis*, or vocal cords, are then closed, and the abdominal muscles contract; but in this case, instead of the diaphragm contracting and bursting open the vocal cords, it *remains fixed* and they remain closed. The cardiac orifice of the stomach relaxes, the muscles and stomach contract still more violently, and its whole contents are forcibly expelled up the œsophagus.

Mechanism of Vomiting.

Vomiting is caused by any irritant to the stomach, or often elsewhere, as in hernia. Also by certain conditions of brain, as in sea-sickness; the centre for vomiting being situated (as usual) in the medulla. Some can vomit voluntarily, and a few have the habit of partly regurgitating the food at will and ruminating like cattle.

Causes of Vomiting.

The sensation of *hunger* is generally referred to the stomach, that of *thirst* to the throat; but both depend on the state of the body cells generally; only the nerves that supply those parts are probably more sensitive to the condition of the blood than elsewhere.

Hunger and Thirst.

In the same way breathlessness from anæmia, though clearly dependent on the state of the blood, is always referred to the lungs.

CHAPTER VI.

SECTION III.—THE FAT OR INTESTINAL DIGESTION.

I. THE INTESTINES.

THE intestinal part of the alimentary tube in man is twenty-seven feet long, the *small intestine* being twenty-one, the *large* six.

Length of Intestines.

Its length in different animals is dependent on the food they take. It is shortest in carnivora, as in the dog, where digestion is quickest, and longest in the herbivora, where digestion

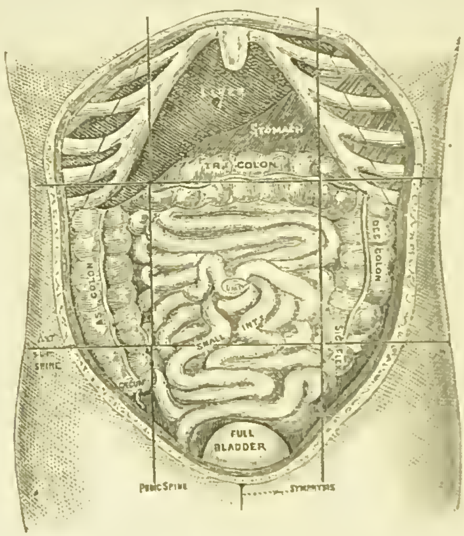


Fig. 47.—Contents of the Abdomen.

is slowest, as in the sheep, where it is about thirty times the length of the body, as against ten times the length in man (measured from the vertex to the buttock).

The **small intestine** is a tube about one inch in diameter, commencing at the pyloric valve, and forming a convoluted mass in the centre of the abdomen, and terminating at the *ileo-cæcal* valve, where it enters the large intestine or colon, a little above the right groin. It is divided into three parts. First, next the stomach, the **duodenum**, the shortest and *widest*, so called because it is the length of the breadth of *twelve* fingers (about one foot long). This curves like a horse-shoe round the head of a digestive gland called the *pancreas*. Next, the **jejunum**, about eight feet long, so called because after death it is generally *empty*; and, lastly, the **ileum**, about twelve feet long.

The small Intestine.

The Duodenum.

The Jejunum and Ileum.

The **colon**, or large intestine, is about two inches in diameter, and may also be divided into three parts—the *ascending*, *transverse*, and *descending*. The first part runs straight up the right side to the lower border of the ribs, the second across from right to left, and the third from the left ribs to the termination of the canal. As it descends it bends into a large double curve like an **S**, called the *sigmoid flexure*, and from thence becomes straight (called the *rectum*), ending at the *anus*.

The Colon.

The Sigmoid Flexure and Rectum.

The intestinal valves are five in number. The *pylorus* is a strong muscular ring that can close completely. The *ileo-cæcal* valve, where the ileum joins the colon, has two flaps that allow passage into the large intestine, but none backwards. The *third* is a circular muscular constriction at the commencement of the rectum that prevents the entrance of the intestinal contents into it, except at times. The fourth is the *internal sphincter*, and the fifth the *external sphincter* of the anus, at the termination of the canal, both being firm muscular rings. The latter has striped muscle fibre.

The five Valves.

2. THE COATS OF THE INTESTINE.

The intestine throughout consists of four coats. The *outer* serous is formed of peritoneum ; the *second*, of muscle, is in two layers, the outer longitudinal, the inner circular, with *Auerbach's* plexus between. This coat is arranged in a peculiar manner in the large intestine, where it is gathered up in three bands that are considerably shorter than the bowel, and gather it up in transverse folds along its whole length.

The four Coats.

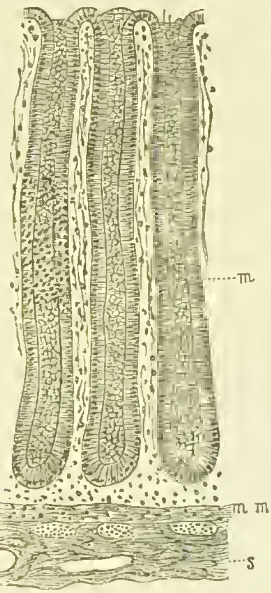


Fig. 48.—From a Vertical Section through the Mucous Membrane of the Large Intestine of Dog.

m, The mucosa, containing the crypts of Lieberkühn, closely placed side by side ; each crypt is lined with a layer of columnar epithelium; *mm*, muscularis mucosæ ; *s*, submucosa.

The circular fibres throughout are thick and strong. The *third* is the submucous coat of loose connective tissue, with Meissner's plexus of nerves. Then we get the mucous muscular (longitudinal) layer, and *lastly* we reach the thick mucous membrane.

The Mucous Membrane.

The first point we notice is that it is raised in sharp, transverse folds, called **valvulæ conniventes,** that do *not* disappear when the canal is stretched. They extend in crescent form two-thirds of the way round, and continue to the lower third of the ileum. Their form greatly retards the passage of food, and they are supposed to exist for this purpose, in order that it may have time to be digested and absorbed.

Valvulæ Conniventes.

3. THE GLANDS OF THE INTESTINES.

We then notice that the whole of the small intestines have a surface like velvet pile, due to innumerable short

elevations placed close together, called **villi**, of which we will speak later on. Between these villi are the orifices of the **crypts of Lieberkuhn**, which sink nearly as deeply below the surface as the villi rise above it. These form one of the three varieties of

The Villi.

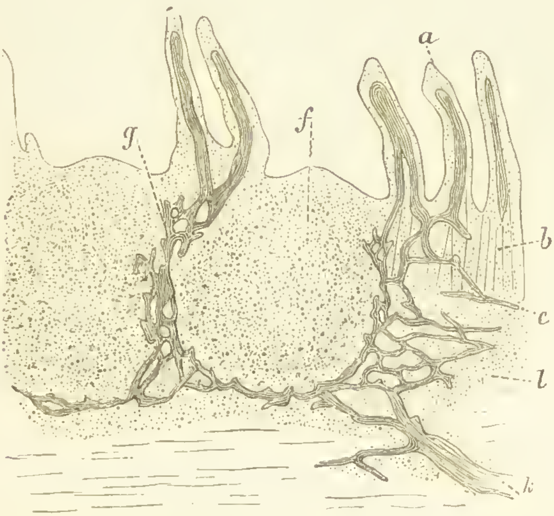


Fig. 49.—From a Section through a part of a Human Peyer's Patch, showing the distribution of the Lymphatic Vessels in the Mucosa and Submucosa.

a, Villi, with central chyle vessel; *b*, Liebekühn's crypts; *c*, region of muscularis mucosæ; lymph follicle; *g*, network of lymphatics around the lymph follicle; *l*, lymphatic network of the submucosa; *k*, an efferent lymphatic trunk. (Frey.)

intestinal glands. They are simple tubes lined with columnar epithelium, and about $\frac{1}{20}$ of a line in depth. They secrete what is known as the *succus entericus* or intestinal juice.

The Glands of Lieberkuhn.

These "*crypts*" do not cease at the ileo-cæcal valve like the villi, but are continued throughout the large intestine. Here they are considerably larger, and contain many mucin cells, so that the secretion is less watery, and more viscid.

The next form of glands is **Peyer's**. These are masses of lymph tissue, occurring either in scattered

masses (*solitary glands*) or in aggregation of these (*Peyer's patches*). They are about $\frac{1}{20}$ inch in diameter, and extend throughout the small and large intestines, but are most numerous near the ileo-cæcal valve. They are traversed by very numerous capillaries, and are believed to absorb some of the chyle, and pass it into the lacteals beneath them. They probably perform some part in the elaboration of the blood. In adult life they nearly all disappear.

Peyer's Glands.

The last form of glands are **Brunner's**, and are only

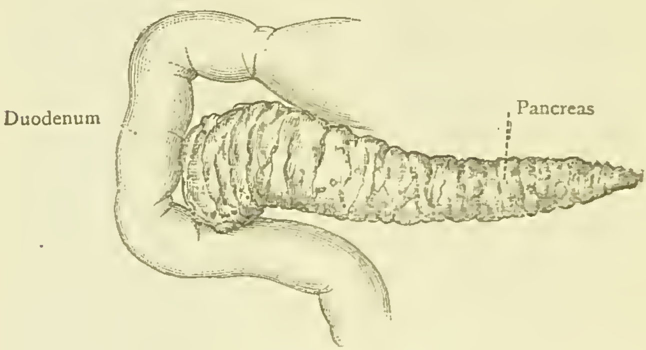


Fig. 52.—The Duodenum and the Pancreas.

found in the duodenum. They are small racemose glands, and look like detached pieces of the salivary glands. They secrete a small amount of digestive fluid, resembling pancreatic juice.

Brunner's Glands.

The intestines contain three forms of digestive fluid: the *pancreatic juice*, *the bile*, and the *intestinal juice*.

4. THE PANCREAS.

The *pancreatic juice* is the product of a gland called the **pancreas** (in animals the sweetbread), that lies across the body, from right to left, behind the stomach, its head surrounded by the duodenum, and

The Pancreas.

lying against the liver on the one side, and the tail touching the spleen on the other. It is somewhat the shape of a hammer, with the handle coming to a point. It is from six to eight inches long, and about one and a half inches broad and thick, and weighs nearly a quarter of a pound.

In structure it resembles closely that of the salivary

Fig. 51.—From a Section through the Pancreas of Dog.

a, The alveoli (tubes) of the gland; the lining cells show an outer homogeneous and an inner granular-looking portion; *d*, a minute duct.

glands. It is, like them, divided into lobes and lobules, ducts, and acini. These are lined with cells arranged in circles round the small ducts. The cells have two distinct zones, the outer being striated, the inner granular, the proportions between the two parts varying with digestion. All the ducts unite in a common duct that opens into the middle of the duodenum together with the common bile ducts.

Its Structure.

5. THE PANCREATIC JUICE.

Composition of Pancreatic Juice.

The **pancreatic juice** itself is a clear, viscid, strongly alkaline fluid, very like saliva, sp. gr. 1015, secreted at the rate of *three-quarters of a pint in the day*. It is the most powerful digestive fluid in the body, and is composed as follows :—

Water	97·0
Proteids (including all four ferments) ...	1·5
Salts (principally of soda)	1·5
	100·0

It contains at least *four distinct ferments.*—

1. To act on starch, *amylopsin.*
2. To act on proteids, *trypsin.*
3. To act on fat, *steapsin.*
4. A *milk-curdling ferment.*

Amylopsin.

Amylopsin acts more energetically than ptyalin. It can act on raw starch and convert it all into dextrin and maltose (like cane sugar). By its further action the maltose is converted into glucose (grape sugar).

Trypsin.

Trypsin digests proteids, not by swelling them up and dissolving them, but by corroding them away. The digestion is, of course, alkaline, in fact, a solution of 1 per cent. sodic carbonate helps it as much as a ·2 per cent. of hydrochloric acid aids the gastric juice. There is an intermediate *parapeptone* produced in the form of an alkali albumen, while the peptones are divisible, as in the stomach, into *antipeptones* that cannot be decomposed, and *hemipeptones*, which, if the pancreatic juice continues to act, are decomposed into *leucin* and *tyrosin.*

Steapsin.

Steapsin has the power of *emulsifying* and *saponifying* the fats and oils. An *emulsion* is simply the mixture of an oil with an alkaline solution by

which it is broken up into very small globules. *Saponification* is the breaking up of a fat into glycerine and fatty acid, which latter combines with the alkali to form a soap.

The **milk-curdling ferment** is easily extracted by common salts. As the pancreatic juice contains many proteids, and as it possesses a ferment that acts upon them, it rapidly digests itself and cannot be kept. Its action is destroyed by the addition of ·2 hydrochloric acid, but is greatly helped by the presence of the alkaline bile. Rennet.

6. THE BILE.

The **Bile** is the second digestive fluid in the intestines, and is a secretion formed by the liver. It enters the duodenum by the same opening as the pancreatic juice, down the common bile duct, at the rate of *a quart a day*. It is a somewhat viscid fluid, of a golden yellow colour, bitter taste, slight alkaline reaction, and with a sp. gr. of 1020. It is composed as follows :— Composition of Bile.

Water	86·0
Bile Salts	9·0
Fat	1·0
Mucus and Colouring Matter	3·0
Cholesterin	·3
Salts	·7
	100·0

Its presence in any fluid is easily detected by **Pettenkofer's Test**, which consists in the addition to the liquid of a drop or two of cane sugar followed by two or three drachms slowly added of sulphuric acid. If bile be present a beautiful purple colour is formed. Pettenkofer's Test.

The *bile salts* are essentially two in number *glycocholate and taurocholate of soda.* Bile Salts.

The colouring matter of human bile is called *bilirubin.* The green colouring matter of the bile of herbivora is called *biliverdin*, which is simply an oxydised bilirubin.

Bilirubin.

The colouring matter of the bile is easily tested for by **Gmelin's** method. If a little of the liquid be placed on a white plate and a drop of yellow (impure) nitric acid be added, a ring of colour is seen in the order of the spectrum, if bilirubin be present.

Gmelin's Test.

Cholesterin forms the principal part of gallstones, and is the only alcohol found in the body. It easily crystallises.

The bile has several actions on the food. In some animals, and very slightly in man, it has the power of changing starch into sugar. It has no action on proteids, but it renders the gastric juices neutral and precipitates the peptones. It slightly emulsifies (but does not saponify) fats, but acts more powerfully when mixed with pancreatic juice. By bathing the intestinal walls it greatly assists the passage of the fat globules across them. It is a powerful antiseptic and a natural laxative. Not more than one-sixteenth of the bile secreted is excreted, and very little of this contains the bile salts.

Action of Bile.

Bile Re-absorbed.

In fœtal life nearly all the meconium (the contents of the lower intestine) is bile; the CO_2 and H_2O, which in adults is passed off by the lungs, probably being excreted as bile instead.

7. THE INTESTINAL JUICE.

The **succus entericus**, principally the product of the glands of Lieberkühn, is a yellow alkaline fluid, sp. gr. 1011, containing 2·5 solids, largely sodium carbonate. It has a slight power of changing starch into sugar, and it freely changes maltose into glucose. Otherwise it has no active properties.

Composition of Intestinal Juice.

8. THE INTESTINAL DIGESTION.

We will now follow the food, which, in the form of acid chyme, has entered the duodenum through the pyloric valves in the third section of the digestive process.

The Digestion in the Duodenum.

The passage of the chyme over the common orifice of the bile and pancreatic juice at once produces a copious flow, and the acidity of the fluid at once begins to be neutralised. It does not, however, become alkaline till about the middle of the small intestine, and it becomes gradually acid again after this, and especially in the colon.

Action of the Chyme.

All the maltose or cane sugar in the chyme is almost instantly changed to glucose. Any undigested and even uncooked starch is made into sugar, proteids into peptones, and the fats into a fine emulsion of a soapy nature by the combined action of the bile and pancreatic juice. While, however, all the sugars and peptones can now freely pass into the network of capillaries over the mucous membrane of the intestine, the globules of fat, small as they now are, are still far too large to diffuse in this manner. A very special apparatus therefore exists for their absorption, which we will now describe.

Action on Starch and Proteids.

Fat Digestion.

9. THE VILLI.

We have already mentioned the rounded elevations of the mucous membrane that project like fingers into the intestine. They average about a line in length, and average about 80 to a square line (or 11,000 to a square inch) in the duodenum, and about 50 in the rest of the small intestines. There are about 4,000,000 in all. They vary in form according as they are full or empty.

Construction of a Villus.

Each is composed of a central tube, communicating below with the lacteal and lymph vessels in the intestinal walls, and ending above in a blind extremity. This tube is surrounded by a thin layer of longitudinal muscle fibre. This is surrounded by blood capillaries in loose connective tissue, then a fine basement membrane on which, at the

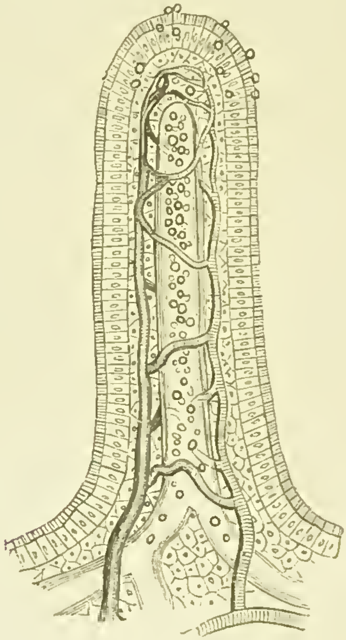


Fig. 52.—Diagram of Villus, with Fat Globules, showing lacteal in centre surrounded by arterial and venous capillaries.

Mode of Absorbing Fat.

surface of the villus, is a single layer of columnar cells. The free surface of these cells has a fine fringed border. Some observers have thought that this consists of processes like the tentacles of the sea-anemone, which grasp the globules of fat and pass them into their interior. They are then conveyed across to the lacteal in the centre. This, however, has never been fully confirmed, and more recent observations (Zuwarykin,

Wiedersheim) favour the idea (supported by the behaviour of leucocytes elsewhere) that leucocytes emerge between the epithelial cells and swallow the fat globules and then convey them across by their own amœboid motion into the lacteal. There may be truth in both views; anyhow, the fact remains that

Action of Leucocytes.

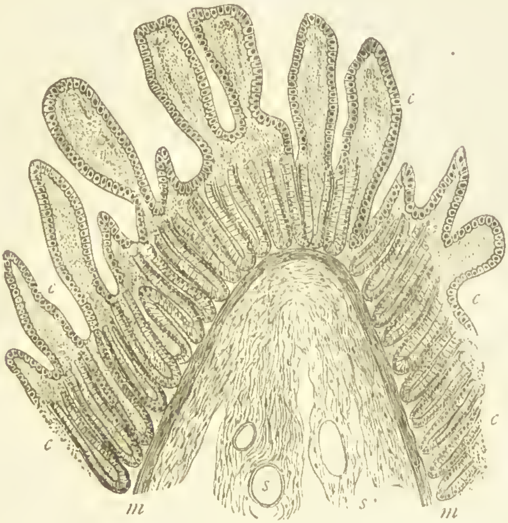


Fig. 53.—From a Vertical Section through a Fold of the Mucous Membrane of the Jejunum of Dog.

c, The mucosa, containing the crypts of Lieberkühn, and projecting as the villi; *m*, muscularis mucosæ; *s*, submucosa.

the fat globules are rapidly conveyed into the central tube, which, when full, is pulled down and squeezed empty by the muscles surrounding it, after which it springs up again to be refilled; the fat passing away with the lymph as a white fluid known as *chyle*. We shall trace its further destination later on.

10. PASSAGE OF FOOD ALONG THE INTESTINES.

As the contents of the small intestines are forced on by the slow peristaltic action of the bowel, all the digested part

of the food gets absorbed, the sugar and peptones into the blood, all to be carried to the liver, and the fat into the lymphatics; and the undigested residue passes on into the colon.

Digested Food Absorbed.

Fig. 54.—Part of a Villus filled with Chyle, from the Intestine of a Puppy four days old. (Heidenhain.)

a, The epithelium of the surface of the villus; *b*, the tissue filled with chyle globules.

In both large and small intestines, besides the food, a good deal of gas is normally present, principally CO_2 and H. It is derived partly from air swallowed with the food and saliva, and partly from the products of decomposition.

Action of the Colon.

The food remains from 3 to 12 hours in the small intestines, and from 12 to 24 in the large. Here the principal function is drawing off the remaining water, and the residue is excreted at the rate of about half a pound a day. This completes the third great section, and the whole process of digestion.

CHAPTER VII.

ABSORPTION.

1. TWOFOLD COURSE OF FOOD.

We must now follow the food that has at length left the alimentary canal and entered the vessels outside, as it is further prepared for use before it enters the general blood current. Course of the Food.

Of the four great divisions of human food, *three*—the carbohydrates, or sugars; the proteids, or peptones; and the salts and water, or minerals, enter the blood capillaries.

All the capillaries of the digestive system from the stomach, and the whole of the intestines close to the rectum, are collected into one large vein called the portal vein, which runs to the liver, thus conveying three-fourths of the digested food.

The fat alone has a different destination. It does not enter the blood-vessels directly, but finds its way by means of the villi into the *lacteals*, which empty themselves into the general lymphatic stream.

(These are so called because the lymph here, being mixed with finely divided fat, closely resembles milk.)

We propose first of all to follow the food through the liver, and then the fat through the lymphatics.

2. THE LIVER.

The **liver** has five letters, five lobes, five ligaments, five fissures, five vessels, five functions, and weighs fifty ounces. It is situated partly under cover of the ribs on the right side of the Structure of the Liver.

body, just beneath the diaphragm, and consists essentially of a mass of *hepatic* or modified epithelial cells, divided into clumps called *lobules* ($\frac{1}{20}$ in. diameter), not visible to the naked eye, separated from each other by fine fibrous tissue, with which the whole organ is invested, and by blood-vessels. Its lobes, ligaments, and fissures fortunately do not concern us now, so we will consider its system of circulation.

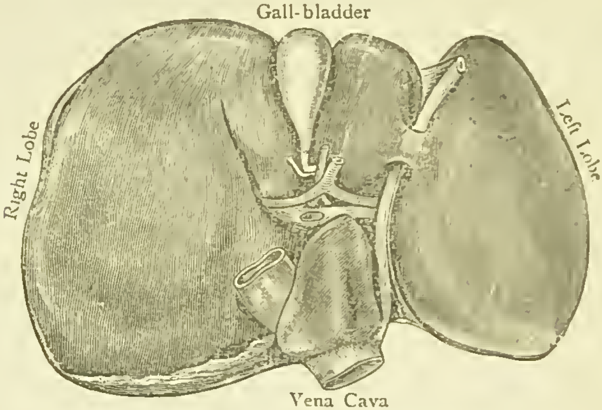


Fig. 55.—The Liver: its Inferior Surface (turned upwards).

Blood Supply.

The liver receives its blood supply from two sources, and returns it to the heart by one. The blood, laden with digested food, enters it by the *portal vein*, and fresh arterial blood for the nourishment of the liver itself by the *hepatic artery*, both leaving by the hepatic veins. The other two vessels are the bile or hepatic ducts, and the lymphatics.

Lobules.

The large portal *vein*, the smaller hepatic *artery*, and the still smaller hepatic *duct*, all enter the liver together and divide and subdivide together, all these being enclosed in a loose fibrous sheath, called *Glisson's* capsule. As they get very small they divide the whole substance

of the liver, which is solid and homogeneous throughout, into little islands or **lobules**, about $\frac{1}{20}$ of an inch in diameter, and each composed of a mass of cells. The portal canals arriving at these lobules branch into small veins which, running *between* these lobules, are called *interlobular* veins. These give off a dense capillary network that runs from all sides of the lobule toward the centre, where they all collect again and leave the lobule by a vein in the centre, which, being *within* the lobule, is called an *intralobular* vein. This vein, together with the lobule, presents somewhat the appearance of a nasturtium leaf, where the stalk enters about the middle; the leaf being the lobule and the central stalk being the intralobular vein bearing it. These intralobular veins collect together and pour all the blood, by the hepatic veins, into the inferior vena cava. The hepatic artery, in a similar manner, breaks into capillaries, which mix their arterial blood with the venous blood of the portal system, and both are collected by the one intralobular vein. The bile ducts, on the contrary, though they, too, enter the lobule in a system of minute capillaries, nowhere mix with or even touch the blood-vessels, but appear to end amongst the cells. Lymphatic spaces everywhere surround the blood-vessels.

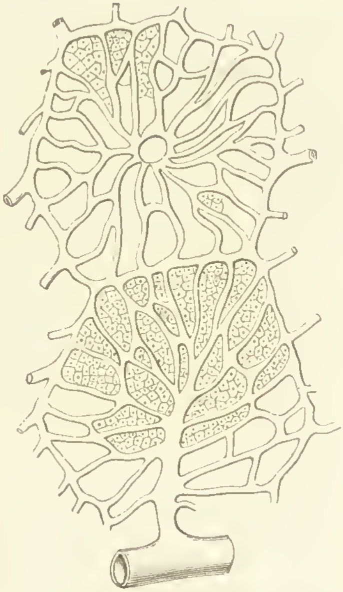


Fig. 56.—Blood-vessels of two Lobules of the Liver.

The circulation of the blood is maintained by special means. The heart is not sufficiently powerful to drive the blood through two sets

of capillaries—those in the alimentary canal, and those in the liver; hence the veins in the liver are not collapsible but always open, and every movement of the intestines drives the blood forward by the collapsing of the abdominal and portal veins, into the open veins of the liver. It is then sucked up into the thorax at every inspiration, through the greatly diminished pressure there, and thus reaches the heart.

Liver Cells.

The **liver cells** are irregular polygons $\frac{1}{1000}$ inch in diameter, and are arranged in double rows, all converging towards the centre of the lobule. Between every two rows a capillary runs, in such a way that the cell has a capillary at each angle, while the bile ducts run half-way along each side so as never to meet the blood-vessels. The cells have no limiting membrane, but have one or two large nuclei, and frequently globules of oil, or masses of digested material, within them.

During hunger the cells are small and very granular. With a free carbohydrate diet they get large and filled with masses of glycogen, which colour red with iodine; with a proteid diet they absorb peptones.

They are said (Leonard) as a whole to grow from July to November. and to decay from December to June.

The cells exhibit slow amœboid movements, and frequently contain yellow granules of bile pigment.

Functions of the Liver.

We will now consider the five functions of the liver, two of which, at least, are very generally known.

Formation of Bile.

The *formation of bile* is *one* of the chief functions of the liver cells. As produced it is passed into the tiny ducts that lie between the opposing surfaces of the cells, and then passes out of the liver to be stored in a special receptacle called the *gall bladder*, which is a strong bag about four inches long, able to hold about one ounce of bile. If digestion is going on at the time, the secretion becomes more active, and the bile, instead of entering the gall bladder, passes straight down

into the duodenum. The properties and purposes of bile we have already described.

The *formation of glycogen* or animal starch is the *second* chief function of the liver. It is a substance isomeric with, or having the same formula as, starch or dextrin, and colours red with iodine. The molecule of water added by the ptyalin changing starch into sugar is here removed, converting the sugar into glycogen. It is readily changed, as required, into glucose by a ferment present in the liver.

Formation of Glycogen.

Barraud discovered this function as follows. He fed a dog for a week on sugar and starch, and found sugar in both portal and hepatic veins. When the dog was fed on proteids only, no sugar was found entering the liver by the portal vein, though plenty was still found coming out by the hepatic vein.

He then found sugar in the liver itself. He then took the liver out of the body and washed it through with plenty of water till not a trace of sugar came out, and yet, after a few hours, it contained sugar again in abundance. Pavy and others, however, believe that glycogen is not converted into sugar during life.

Glycogen is formed slowly from protcids as well; probably by splitting them up into glycogen and urea. It is found that only half as much glycogen is found in the liver on a pure meat as on a mixed diet.

The object of the formation of glycogen, which is not diffusible, is clearly to store up the soluble sugar in the liver, thence to be remade as required into glucose.

Use of Glycogen.

Glycogen has been found in small quantities in other tissues of the body.

The conversion of glycogen into sugar is increased by puncture of the floor of the medulla (fourth ventricle), by excess of saccharine food, by certain drugs such as curarc. Increased blood-flow occurs at the same time through the liver.

Formation of Blood.

The *third* function of the liver is in the *formation* in fœtal life *of the red corpuscles of the blood*, and in adult life in also altering its composition. It is found that the blood that leaves the liver contains less water and fibrin, but more colourless corpuscles than elsewhere.

It is probable also that many red corpuscles are broken up here, and that it is from them that bilirubin is produced.

Formation of Ferment.

The *fourth* function of the liver is the *formation of the diastatic ferment* that changes the glycogen into glucose. It only exists in minute quantities in health.

Purifying the Peptones.

The *last* function of the liver is the *purifying of the peptones* (all of which, in the form of serous albumen, pass through it) from all poisonous and deleterious products of digestion. (Brunton.)

This last function, when more fully understood, will probably be seen to be of great importance in connection with the great question of *autosepsis* or self-poisoning (producing bilious attacks, etc.).

3. THE LYMPHATIC SYSTEM.

The Lymphatics.

Within the whole of the tissues of the body surrounding all the capillaries, and existing where there are no blood-vessels, is a vast network of tubes containing the liquid drainage of the body, which flows through all those vessels always towards the head. The lymph capillaries collect into larger lymphatics, and eventually enter two large trunks, the right and left *thoracic ducts*, that enter the veins on each side at the root of the neck. Just as all the body cells and tissues are being continually *irrigated* by the capillaries, whose thin walls allow the fluid to transude, so are they constantly being *drained* of the surplus fluid by the lymphatics.

Uses of Lymphatics.

Besides this general use, they have at least two other special purposes.

1. They act by the lacteals, as we have seen, as absorbents of "fat" food; and

2. In some tissues they form (where there is no blood supply) the sole source of nourishment, as in the cornea of the eye and many connective tissues.

The whole system may be regarded as a necessary

Fig. 57.—The Lymphatics of the Right Arm.

appendage to the vascular system. Nevertheless, it is convenient to treat it under the head of absorption in order to complete the history of food digestion.

Lymphatic Vessels.

The lymphatics commence everywhere as capillaries in spaces generally surrounding blood-vessels. They have very thin and irregular walls, and often appear mere channels hollowed out in the surrounding tissues.

The main tissues in which they have not yet been found are the nails, scarf skin, and hair. They may commence, as we have seen, in blind extremities, as the lacteals in the villi, or from stomata or mouths on the walls of the large closed serous sacs, with the interior of which their openings or mouths connect them. So that what were until recently supposed

Origin in Serous sacs.

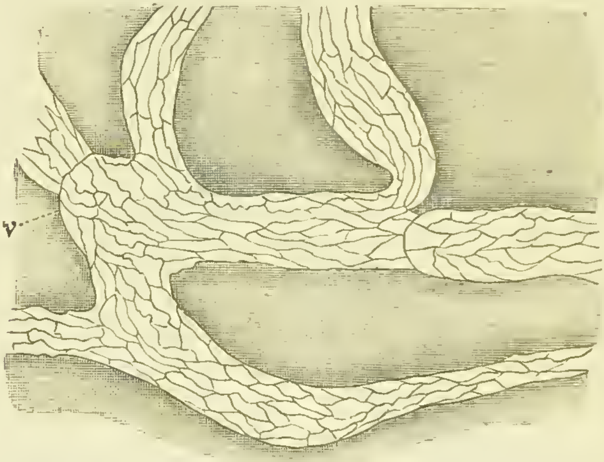


Fig. 58.—Lymphatic Vessels of the Diaphragm of Dog, stained with Nitrate of Silver. The endothelium forming the wall of the lymphatics is well shown; *v*, valves.

to be absolutely closed cavities, are now found to be sources of origin and supply for the lymphatic system, with which they everywhere communicate. The pleura, the pericardium, the peritoneum, and the membrane of the brain, all these can get rid of their surplus fluid by this great drainage apparatus.

Some give yet a fourth mode of origin—viz., the free surfaces of mucous membrane in the bronchi and the trachea, from which they receive the surplus fluid.

These capillaries unite and form larger vessels with the structure of veins, only the valves in them are so very

numerous that when distended they resemble strings of beads rather than a continuous vessel.

The movement of the lymph towards the heart is *first* due to muscular pressure and the very numerous valves. The collapsible lymphatics, whether amongst the voluntary muscles of the neck or the unstriped muscles of the intestines, have their contents therefore forced in one direction. A *second* force is the

Lymphatic Circulation.

Fig. 59.—Stomata, lined with Germinating Endothelial Cells, as seen from the Cisternal Surface of the Septum Cisternæ Lymphaticæ Magnæ of the Frog.

direct act of the muscles surrounding each lacteal in the villus, by which when full its contents are ejected into the vessel beneath, valves again preventing its return. A *third* force is the inspiratory movement of the chest, which both forces the pleural fluid out of the stomata into the lymphatics and sucks the fluid of the larger ducts into the blood stream.

A direct pumping mechanism exists in connection with the lymphatics in these closed sacs, and also in muscles and the fascia (or fibrous tissues covering them). It has been found (Recklinghausen) that milk placed on the abdominal side of the diaphragm is thus in its respiratory movements pumped through into the thorax: the expansion of the

muscle by drawing its fibres apart sucks the lymph up, and then in contracting forces it forward. The same process occurs in all the other muscles and in the layers of the pleura and other closed sacs, so that the fluid in all cases is sucked up as the layers expand, and forced on as they contract.

A *fourth* force is the tension and pressure of the fluid in

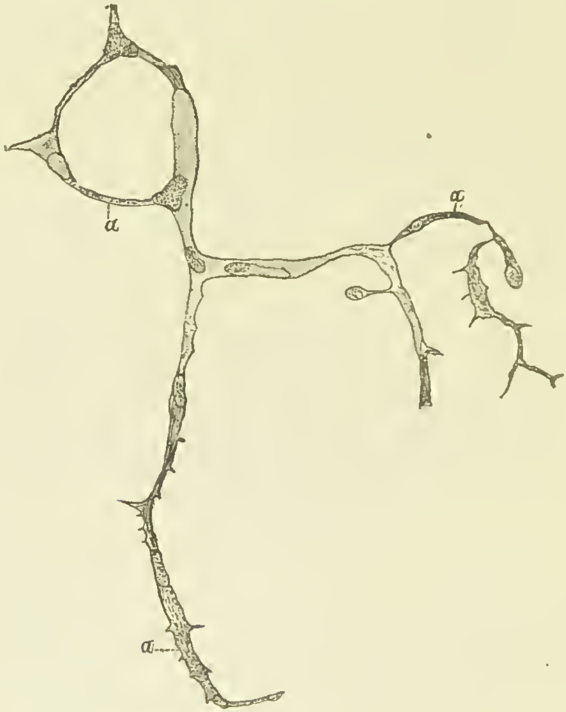


Fig. 60.—Developing Lymph-capillaries in the Tail of Tadpole.
a, Solid nucleated protoplasmic branches not yet hollowed out.

the initial lymph spaces, due to the amount of blood pressure; and also when these surround blood-vessels to the dilatation of the capillaries.

A *fifth* force is the contraction of the muscles in the walls of the larger lymphatics, which, owing to the valves, always forces the fluid on.

A *sixth* force is the diminishing area of the total lymph channel, thus increasing the velocity of the flow. The *seventh* and last force is the nervous system, which has the power to alter the calibre of the vessels and to act upon their muscles.

All the lymphatics of the body, with the exception of a

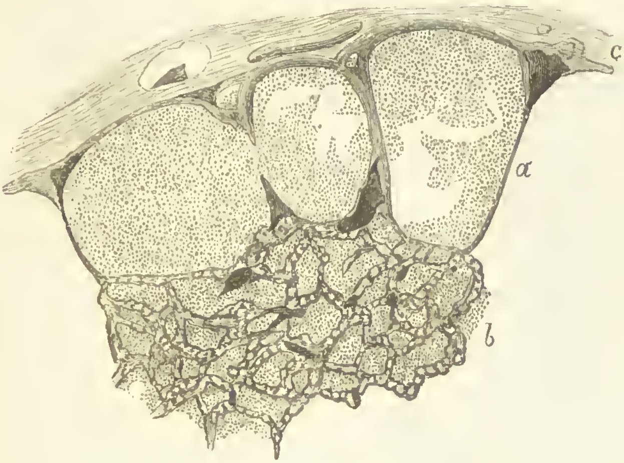


Fig. 61.--From a Vertical Section through a Lymphatic Gland, the Lymphatics of which had been injected.

c, The outer capsule, with lymphatic vessels in section ; *a*, the cortical lymph follicles ; around them are the cortical lymph sinuses ; *b*, the medullary; injected lymph sinuses between the masses of adenoid tissue. (Atlas.)

few from the right side, but including all the lacteals, discharge their contents (after passing through numerous lymphatic glands *en route*) into a large triangular or funnel-shaped reservoir called the **receptaculum chyli**, lying in the abdomen at the lower part of the spine at the left side. From here a stout tube, as thick as a goose quill and about eighteen inches long, called the *left thoracic duct*, leads right up the left side, and empties its contents at the juncture of the neck and arm (jugular and subclavian) veins, thence to be carried to the right heart.

The left Thoracic Duct.

The small right thoracic duct is not more than an inch long, and empties the remaining lymphatics into the corresponding right veins. Both orifices are guarded with valves, so that no blood can enter the duct.

Nearly all the lymph before entering the duct has to pass through one or more lymphatic glands. They are found in great numbers in the trunk of the body, in the neck, armpit, and groin, but not further down the limbs than the elbow or knee. These glands are somewhat the shape of small beans, lying right across the path of the lymphatics, with the convex side outwards or downwards, along which the lymphatics enter, while the lymph leaves it at the hilum or depression on the other side by one or two larger vessels.

Lymphatic Glands.

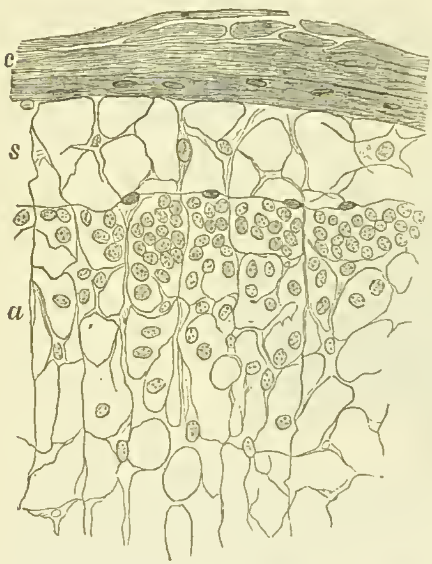


Fig. 62.—From a Section through a Lymphatic Gland.

c, The outer capsule; *s*, cortical lymph sinus; *a*, adenoid tissue of cortical follicle. Numerous nuclei, indicating lymph corpuscles.

The gland has a capsule of dense fibrous tissue, which extends inwards about half-way, dividing the outer or cortical portion into a number of spaces: into these projects the gland substance proper, which is a mass of adenoid or lymphoid tissue (lymph corpuscles and a network of connective tissue). There is a space between the lymph tissue and the capsule, traversed only by a fine network, and this is where the lymph first circulates, and is called the *lymph path*. It then soaks through the cortical

Structure.

tissue, enters the medullary or central part, and, eventually, altered in character, leaves by the effluent vessel. There is reason to believe the functions of these glands are of the very first importance to life; as any poison entering the system at any part cannot go far after it is absorbed by the lymphatics, without encountering

Functions.

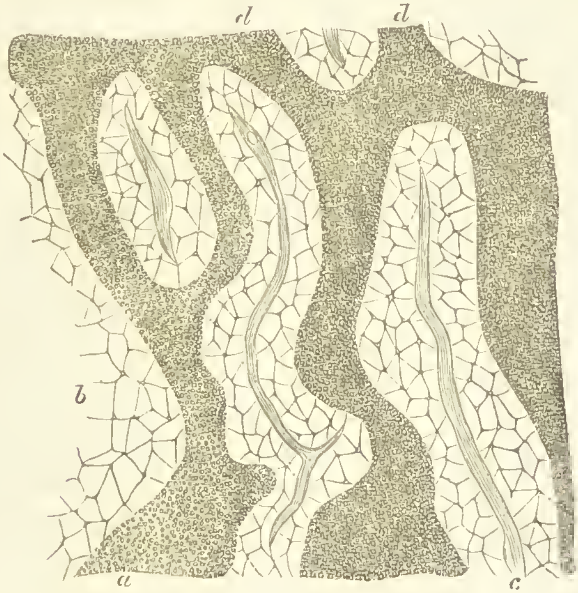


Fig. 63.—From a Section through the Medulla of a Lymphatic Gland.
a, Transition of the medullary cylinders of adenoid tissue into the cortical follicles; *b*, the lymph sinuses occupied by a reticulum; *c*, the fibrous tissue trabeculæ; *d*, the medullary cylinders.

some of these so-called glands. All the poison is here arrested, and the irritation caused to the gland is often so great that it enlarges and becomes itself diseased.

Thus if a finger be poisoned the gland at the fold of the elbow becomes enlarged and tender, and if this little gland be not able to arrest all the poison the rest goes up the arm to the axilla, where it is caught in the glands there.

Chyle (or lymph from the intestines) and lymph are

alike, save during digestion, and are clear alkaline, colourless, albuminous fluids, with a saline taste, and can clot like blood. Lymph consists of two parts, plasma and colourless corpuscles. The plasma contains the fibrous factors that cause the clot. The following is the composition of lymph :—

Chyle and Lymph.

Water	98·0
Albumen	·2
Urea, etc.	1·0
Salts	·8
	100·0

The lymph contains few corpuscles at first, but many more after it has passed through a gland. *Chyle* during digestion is laden with innumerable fat globules, $\frac{1}{31000}$ inch diam., sheathed in an albuminous covering. Lymph contains a good deal of CO_2. The estimate that the amount of lymph equals that of the blood, of which half is lymph and half chyle, is only a very rough one, and is probably over the mark.

We have thus finally traced the passage of the food out of the blood; the salts, the proteids and carbohydrates, being elaborated and stored by the liver and blood, and the fats by the lymphatic system.

CHAPTER VIII.

THE BLOOD.

THE blood is a *heavy*, *red*, *opaque*, *warm*, *alkaline*, *saltish* fluid, with sometimes a faint *odour* characteristic of the animal it belongs to. It is emphatically "the life of the body," in the sense that upon it depends the existence of the body. It is the sole means by which the compound and complex products of digestion on the one hand, and oxygen on the other, are conveyed to all the tissues and to every body cell, there to be reduced to simple forms of less complex nature; the force liberated in the process being partly used in the passive life of the cells, and partly in the various active phenomena. The blood is therefore the carrier between the digestive and respiratory organs on the one hand, and the living body cell on the other; the blood-vessels in which it is conveyed forming at the same time a complete warming apparatus for the body.

Charac-teristics.

We will first consider its seven leading characteristics.

Seven in Number.

HEAVY.—It has a mean specific gravity of 1056 (varying between 1045 and 1075).

RED.—Its colour varies from bright scarlet to dark purple. In the *arteries* it is bright red, and also whenever exposed to the air.

Hence it is bright red in the surface capillaries just beneath the skin of the cheek, and wherever this is thin enough to receive oxygen from the air.

In the *veins* it varies from dark purple to red, getting brighter in proportion to the activity of the part or organ whence it comes. (The activity causes such an extra

supply of blood from the arteries that the blood has not time to change colour.)

Venous blood is *dichroic*, or of two colours. It is red or purple by reflected light, but dark green by transmitted light. Arterial blood is monochroic, or of the same colour either way.

The colour of the blood is entirely due to a red substance called *hæmoglobin*, which gets brighter or darker as it contains more or less oxygen.

Opaque.—Blood is opaque even in very thin layers, because it is composed of a solid and a liquid, both transparent, but having different refractive powers, and therefore forming an opaque fluid.

Warm.—The average blood heat near the surface of the body is $98\frac{1}{2}°$ Fah., and is about the same in health in all temperatures; "warm-blooded" animals having a constant blood-heat, independent of their surroundings, in contradistinction to "cold-blooded" animals, whose blood is not necessarily "cold," but varies with the surrounding medium.

The temperature of the blood in the deeper vessels is said to range between 100° and 107°. The blood is hotter in the right heart than in the left, in the arteries than in the veins, in the hepatic than in the fœtal circulation. Its temperature is also increased in passing through large glands, notably the liver.

Alkaline.—If litmus paper be dipped in salt and water and then in blood, and the blood washed off, it will leave the red paper blue, showing it is alkaline from the salts of soda it contains. Out of the body it soon becomes neutral. then acid.

Saltish.—The blood has a slight saline taste.

Odour.—This can best be perceived by adding a little dilute sulphuric acid to the blood. The characteristic odours of domestic animals may thus sometimes be detected.

The *quantity* of the blood may be taken as about $\frac{1}{13}$ of

the weight of the body, a quarter of which is contained in the heart and lungs and large vessels, a quarter in the liver, a quarter in the muscles, and a quarter in the other vessels.

Composition.

Blood consists, as we have said, of both a solid and a liquid. The solid part consists of small bodies called *corpuscles*, the liquid of a fluid called *liquor sanguinis* or *plasma*. The corpuscles form about $\frac{1}{3}$ or 37 per cent., with a sp. gr. of 1104, and the plasma $\frac{2}{3}$ or 63 per cent. with a sp. gr. of 1027.

Two great varieties of blood corpuscles are generally recognised, the red and the white, or, more correctly, the colourless.

The existence of a third variety (invisible by ordinary observation) is asserted by Mr. Norris, and has also been described by Bozzezero, but requires further confirmation.

I. BLOOD CORPUSCLES.

Red Corpuscles.

The human **red corpuscle**, discovered by Lewenhock in 1674, is a circular, biconcave, non-nucleated yellow disc $\frac{1}{126}$ mm. in diameter ($\frac{1}{3500}$ of an inch): 5,000,000 of them are contained in a cubic mm. of blood, while altogether they present a surface of some 3,000 square miles.

The red corpuscles are conveniently counted by drawing 1 cc. of blood up a special pipette and then 100 cc. of artificial serum (1 part so. gum, sp. gr. 1020, and 3 parts of sol. sodium chloride, and of sodium sulphate equal parts, sp. gr. 1020). A drop of the mixture is then placed on a prepared slide with a square cell 1 mm. deep ruled into squares, so that the space on each square when the cover-glass is on is $\frac{1}{400}$ cubic mm. By now finding the

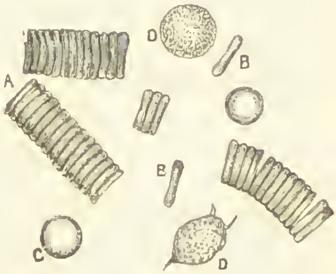


Fig. 64.—Human Blood, fresh.
A, Rouleaux of Red Corpuscles; B, Isolated Red Corpuscle seen in profile; C, Isolated Red Corpuscle seen flat; D, White Corpuscles.

average number of red corpuscles in each square, and multiplying by 4,000 and then by 100, the number of corpuscles in one cubic millimetre of blood is found. To estimate the colourless corpuscles only, the blood must first be deprived of the red corpuscles by mixing it with 10 parts of ·5 per cent. sol. of acetic acid.

The size of the corpuscle varies somewhat in different mammals according to their size. It is thus largest in the elephant $\frac{1}{2700}$, and smallest in the musk deer $\frac{1}{6300}$; only the sloth and the elephant, however, have larger corpuscles than man. In camels they are oval instead of round.

When we leave mammals, instead of colourless corpuscles, and circular red corpuscles without nucleus, we find amongst the lower vertebrata, such as birds, reptiles, and fish, that the red corpuscles are oval and have nuclei, except in the lowest of this class, the Lancelet, which has the colourless corpuscles only. In the invertebrate animals that have blood there are only the colourless corpuscles. The largest red corpuscle ($\frac{1}{400}$ of an inch) is found in the proteus.

The red corpuscle is composed of a stroma or framework of protoplasm, holding in its meshwork a transparent viscid homogeneous substance called *hæmoglobin*. The discs are generally biconcave, but as they readily imbibe water, often swell up and become more or less spherical. They are exceedingly elastic, and more numerous in the male than in the female. They have a great tendency, when the blood is drawn, to run together in rouleaux, like piles of coin. They are yellowish in colour, and only present the red tint of blood when seen in masses. (Fig. 63.)

Their numbers rapidly diminish in certain diseases. In anæmia there may be only one-fourth of the number in health.

Hæmoglobin.

Hæmoglobin forms 90 per cent. of the dried blood corpuscle, and is the only albuminous substance that crystallises. It contains CHNOS and Fe, and is a compound of hæmatin and globulin, and occurs in the red blood-cells of every animal. It is one

of the most complex bodies known, its formula being $C_{600}H_{960}N_{154}FeS_3O_{179}$.

Hæmoglobin crystallises naturally as it dries (or with the addition of a little salt and a drop of glacial acetic acid) in brown rhombic crystals (crystals of hæmatin). Another characteristic of hæmoglobin is its remarkable affinity for oxygen; owing to this the blood absorbs twelve times as much oxygen as water. The hæmoglobin holds this gas in a very loose form so as to part with it readily. As the blood passes through the lungs

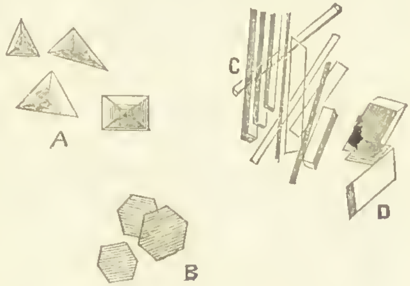


Fig. 65.—Hæmoglobin Crystals.
A, Of guinea-pig; B, of squirrel; C, D, human.

it receives oxygen, and the hæmoglobin becomes oxy-hæmoglobin as in arterial blood; then, again, as it reaches the tissues, the oxygen leaves it and it is reduced to hæmoglobin. It is in this way the blood is the great oxygen carrier of the body. In the solar spectrum oxy-hæmoglobin shows two dark lines (or absorption bands) in the yellow field, and hæmoglobin one broad one. (Fig. 67.)


Fig. 66.—Hæmatin Crystals.

Formation of Corpuscles.

The life-history of the red corpuscle is not certainly known. The first blood corpuscles are formed from detached cells in the embryonic heart and blood-vessels. These are colourless and nucleated. They soon become red, and in a short time are mixed with numerous coloured non-nucleated corpuscles, which about the fifth month of fœtal life completely replace them, forming the red corpuscle of after life. It is uncertain whence these red corpuscles come before birth. After birth the blood is stocked from probably two great sources. The one refers to the small cells in the red marrow of bone,

and here the real *hæmatoblasts* or parents of the corpuscles are believed by many to be found; others again, recognising that the red corpuscle, as it is, appears to be the naked nucleus of a larger cell, believe that it is derived from the nucleated white corpuscles of the blood, either by the formation of hæmoglobin in the nucleus, and its liberation from the rest of the cell, or by the whole cell becoming

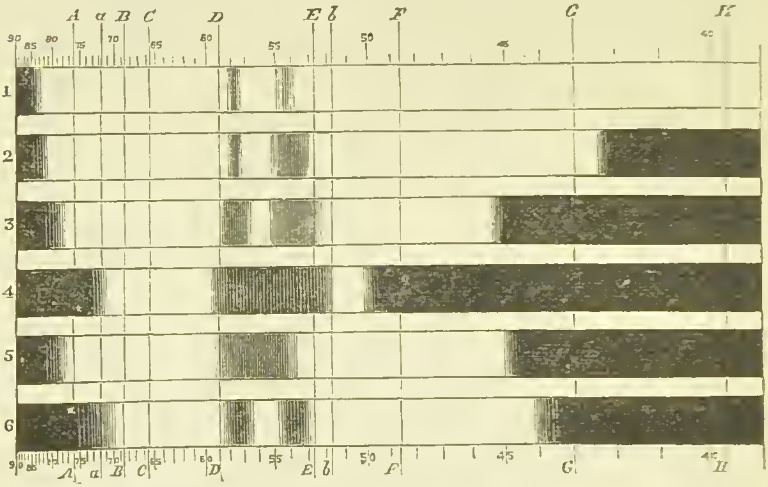


Fig. 67.—Spectra of Blood.

1, 2, 3, 4, Oxyhæmoglobin increasing in strength or thickness of solution; 5, Reduced Hæmoglobin; 6, CO_2 Hæmoglobin.

reddened and forming the new corpuscle; this change occurring principally in the spleen and marrow. The direct evidence in favour of either process is not yet very clear. There can be no doubt that fresh red corpuscles are made with great rapidity. After the monthly loss in women it is computed they are formed at the rate of 175 millions a minute (Power). As to the length of time these red corpuscles pursue their useful avocation of fetchers and carriers of oxygen, we have no idea. Their decease seems to a great extent to take place in the spleen, where they appear to be devoured in large numbers by the larger white corpuscles

there; the colouring matter being broken up and forming the bile pigment, and probably the colour of the urine.

The red corpuscles are more than half water (68 per cent.). The rest is composed of hæmoglobin, hæmatin and globulin, salts of phosphate of potassium, sodium and calcium, fatty matters (including cholesterin) and gas, principally O.

Chemical Composition.

The colourless or white corpuscles (discovered by Hewsen, 1773) are larger than the red, $\frac{1}{2800}$ in. diam.), but are only spherical in death; during life their shape constantly varies. Their numbers are about 1 to 500 of the red, or about 10,000 in a cubic inch. Like the red corpuscles, they have no

Colourless Corpuscles.

Fig. 68.—Amœboid movement of a White Blood Corpuscle of Man; various phases of movement.

cell walls, but unlike them they have one or more distinct nuclei. They have a finely granular appearance, which on examination under a high power is seen to be due to a meshwork that pervades them, the corners of the meshes being formed into knobs. Part of the granules may be food material. The colourless corpuscles or leucocytes of the blood are identical with the smaller description of lymph cells that are found all over the body, and particularly in the spleen and lymphatic glands.

The function of these cells has long been obscure, and is only now beginning to be understood. The last utterance of a leading physiologist (Landois) is that they do "an important work in the blood of an uncertain character." Austin Flint says "their

Their functions.

use is doubtful." We have seen that they are believed to be the parents or forerunners of the red corpuscle. They have very active habits during life. Having the power of traversing the walls of the blood-vessels with the greatest ease into the lymph space around, or the body tissues, they are found in enormous numbers wherever any active inflammation is going on, and they form the principal part of pus or "matter."

Metschnikoff regards them as our defenders against germs of all sorts, and has lately shown how active they are in eating and destroying bacteria and germs, and also refuse of all sorts; while the curious fact has been discovered that in Peyer's patches in the intestines, where they abound, they migrate into the tube, seize on all the bacteria they can find, carry them down into the deeper tissues, where they and their spoil both become the prey of the larger description of lymph corpuscle which we have already alluded to in the spleen as feeding on the used-up red corpuscles.

Enough has been said to show what a life of varied interest and usefulness they lead, and to encourage us to hope for still further discoveries respecting it.

They increase rapidly by fission, and appear in amazing quantities in a very short time wherever they are wanted.

Their Qualities.

One great source of them is the spleen, as seen in the splenic vein, where they number 1 to 80 of the red. Another is the thoracic duct, for it is found that they vary from 1 to 800 red corpuscles when fasting, down to 1 to 300 after a meal; the increase being due to the large numbers poured into the blood by the chyle through the thoracic duct.

Their numbers in certain diseases are enormously increased.

The most remarkable feature about these corpuscles is their constant change of shape (which is always very irregular) by so-called "*amœboid*" movement, from its similarity to that of the "amœbæ" of stagnant waters. This movement is best seen by drawing a cell under the

microscope in a warm stage at intervals of a minute, when it will be seen never to be twice alike. The colourless corpuscle is composed of albuminoids, lecithin, glycogen, myosin (which, coagulating, makes them firmer in death), salts of potassium and phosphorus, and water 90 per cent.

A third variety of corpuscle, invisible in ordinary observation owing to its having the same refractive index as the liquor sanguinis, has been observed and even photographed (Norris), but requires further confirmation. Other Bodies.

The blood also contains *blood plaques*, or plates of different sizes and irregular shapes, averaging one to ten of the red corpuscles, and whose use is at present unknown (Bizzozero).

The liquid part of the blood, known as **liquor sanguinis**, or *plasma*, forms two-thirds of the whole. It is a clear yellow alkaline fluid, sp. gr. 1037. It is nine-tenths water; the remainder being made up of albumens, fats, glycogen, colouring matter of a different nature from hæmoglobin, sodium salts, extracts as urea, and gases, principally CO_2. Liquor Sanguinis.

2. COAGULATION.

When blood is drawn it is first quite fluid; in two minutes it becomes viscid, in five minutes a firm clot is formed, and in ten minutes it is of a buff colour. In a horse, or in inflammation, the blood contracts more slowly and allows time thus for a red corpuscle to sink. The clot is of a buff colour at the top, where it is formed of plasma alone.

This power of clotting or coagulating is the great peculiarity of the blood. It is produced by the rapid formation as it dies of a meshwork of fine white fibres called *fibrin*, which bind the more solid part of the mass, including in blood the corpuscles, together; forming a *clot*, a thin watery fluid being left called *serum*. Coagulation.

It is found that coagulation is *deferred* by the exclusion of air, by strong acids, by an alkaline saline solution, by the living healthy lining of the blood-vessels, by the addition of more than twice the bulk of water, by cold, or by heat above 180° C. Coagulation is *hastened* by the presence of foreign bodies, by a heat of 100° to 120° F., by stasis of blood, by air, and by the addition of a little water, or any injury to the blood-vessels.

Fibrin.

That the fibrin is a product of the plasma and not of the corpuscles is plain, because it is formed when no corpuscles are present; and, on the other hand, if the fibrin be removed or the blood be defibrinated by whipping it with twigs, and the corpuscles and serum are left, no fibrin or clot will be formed.

Fibrin does not, however, exist *as such* in the plasma, but is formed from two albuminous bodies which are found there, united by the power of a ferment. The two bodies that form it are called *paraglobulin* and *fibrinogen*. Fibrin is insoluble in water. It forms ·2 per cent. of the blood.

Paraglobulin.

Paraglobulin is so called because it is like the globulin in the red corpuscles. (Globulin is also found in the eye and other structures.) It is found in serum, and can be thrown down as a flaky precipitate by the addition of a solution of neutral salt.

Fibrinogen.

Fibrinogen is often found by itself in serous fluids of the body, such as are found in the pleura or pericardium (these consist of blood, without the corpuscles, and will sometimes clot, but sometimes will not), also in hydrocele fluid. If a solution of a neutral salt be added to this serous fluid that will not clot, it gives a large flaky precipitate, which is fibrinogen.

Thus, if to the serous fluid a little serum of blood be added, a clot is formed at once. Pure blood serum and pericardial fluid may be kept in separate vessels a long time without clotting, but if mixed they clot at once.

Both bodies are, of course, contained in the plasma, as well as the *ferment*, and are found as follows :—

Experiments.

If CO_2 be passed through diluted ice-cold plasma, you get a fine white precipitate of *paraglobulin*. If CO_2 is again passed through the liquid left, still further diluted, you get a viscid precipitate of *fibrinogen*. If the blood when shed be at once raised from 36·6 C. to 56 C., it gives a precipitate of fibrinogen, and it will not clot. It is found that paraglobulin and the ferment in the blood will not form fibrin without fibrinogen ; but on the other hand, fibrinogen and the ferment will form a sort of fibrin without the paraglobulin. The ferment is only found after the blood is shed. It has no power to clot living blood, or blood in a living artery. If it be injected into such blood, it will not clot it ; but a little added to a plasma so diluted that it will not otherwise clot, will clot it at once. Blood can be kept fluid in a bit of artery like a test-tube for days. If taken out any time it clots at once, or if placed in a living vessel not intended for blood, such as a ureter, it clots also. Blood is always ready to clot in the body, as it will clot round a thread or needle or any foreign body. Certain substances can make it clot readily even when alive. If a piece of the thymus gland of a rabbit be injected into the blood, it will clot all the blood in the body.

Schmidt believes that all these fibrin factors are formed from the breaking-up of the colourless corpuscles. There is no doubt they are helpful to coagulation. The fibrin ferment may come from them, and in their breaking-up at death may be discharged, as well as paraglobulin, into the blood, which already contains fibrinogen.

The coloured corpuscles may also aid in the process, for it is found that serum which will not clot, will do so on the addition of red corpuscles.

That clotting is not a vital process is evident from the fact that, as we have seen, the clotting principle can be thrown down from blood that may have been kept from

clotting some days by cold, and these precipitates if dissolved will at once form a fibrinous clot.

Analysis of Blood.

The following is an analysis of the blood :—

Blood.

Corpuscles. Plasma.

Clot. Serum.

Corpuscles. Fibrin.

Hæmoglobin. Stroma. Fibrinogen. Paraglobulin. (and Fibrin Ferment.)

Globulin. Hæmatin.

Composition of Blood.

The chemical composition of the blood is as follows :—

Of the blood as a whole—

Water	78·5
Corpuscles	13·0
Proteids in Serum	7·0
Fibrin	·2
Fat	·1
Salts	·6
Gases, Kreatin, and Extractives	·6
	100·0

Of the plasma—

Water	90·0
Proteids	9·0
Salts	·8
Fats and Extractives	·2
	100·0

Plasma contains egg and serum albumen, acid and alkaline albuminates, paraglobulin and fibrinogen, fatty matters and neutral soaps, glucose, a colouring matter (indican), salts (chiefly sodium, also potassium, calcium, and magnesium salts), extractives (urea, kreatin, etc.) ; gases, N, O, CO_2, and a volatile odour.

Of the serum—

Water	90
Serum, Albumen, Paraglobulin	8
Salts, Fats, Extractives, Gases, etc. ...	2
	100

Of the corpuscles—

Water	68·8.
Hæmoglobin	28·5
Proteids	2·0
Potassium chloride	·3
Potassium Phosphate	·2
Fats, other Salts, Sodium, Calcium, etc. ...	·2
	100·0

It is a remarkable fact that the elementary composition of blood is the same as that of the flesh or muscle, in its proportion of C, H, N, and O, showing thus how perfectly it is adapted to be the food of the tissues.

The amount of water varies from 70 to 79 per cent. However much or little fluid is drunk, it tends to uniformity, for any excess is rapidly drained off by the kidneys, while any deficiency excites intolerable thirst.

The gases in the blood are as follows:—

	O	CO_2	N	
Arterial blood	20% ...	39% ...	1 to 2%	volumes.
Venous blood	10% ...	46% ...	1 to 2%	,,

Gases in Blood.

O is nearly all contained in the hæmoglobin.

CO_2 is nearly all contained in the serum, partly dissolved and partly in combination with soda. Nitrogen is simply dissolved in the blood. While blood absorbs twelve times as much O as water, serum alone only absorbs the same amount, thus showing that the real oxygen carriers are the red corpuscles.

CHAPTER IX.

THE BLOOD-VESSELS.

I. THE ARTERIES.

THE blood is contained in a system of pipes called blood-vessels. These are of three varieties—*arteries*, *veins*, and *capillaries*.

Blood-vessels Generally.

The arteries convey the fresh blood from the heart to every part of the body. The veins return the blood to the heart from the body, and the capillaries unite the ends of the arteries with the beginning of the veins.

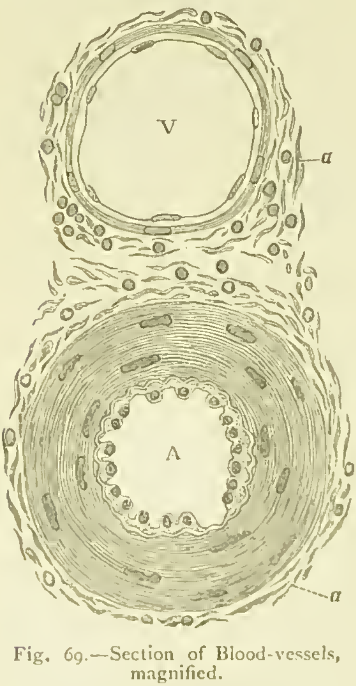


Fig. 69.—Section of Blood-vessels, magnified.
A, Artery ; V, Vein.)

The blood-vessels all lie in a bed of connective tissue, which consists, as we have seen, of a mass of white fibrous cells, with amœboid cells or leucocytes embedded in it.

Construction of an Artery.

An **artery** is a stout elastic tube (sufficiently so to retain its shape when empty), composed of three coats or layers. The innermost, called the *tunica intima*, consists of a layer of flat cells, forming a smooth and polished surface, arranged on an elastic basement, like fine

felt. The middle coat, called the *tunica media*, consists of a layer of transverse, or spiral layer of smooth muscle fibres, mixed with yellow elastic tissue; and the outer, or *tunica adventitia*, is extremely strong and tough, and consists of a tightly woven layer of white fibrous tissue, closely connected with the bed of connective tissue in which the artery lies.

Size of Arteries.

In calibre they vary from the aorta, the large single artery that leaves the heart, down to tubes so fine as to be only just visible to the naked eye. Commencing at this single artery, the tubes divide and subdivide like the spreading branches of a great tree, until they appear to terminate in all the tissues of the body. The larger the artery the thicker is the middle coat, except in the aorta, where the external coat, in which are also large numbers of yellow elastic fibres, is enormously thickened. The inner coat of the artery is nourished by the blood in the vessel; the other coats by small blood-vessels that run in the walls, called *vasa vasorum*.

Fig. 70.—Minute Microscopic Artery.
e, Endothelium; *i*, intima; *m*, muscular media, composed of a single layer of circularly-arranged non-striped muscular cells; *a*, adventitia.

Value of Elasticity.

The elasticity of the arteries is needed on account of the blood being propelled in powerful jerks, thereby producing a good deal of pressure and tension of the walls, which their elasticity enables them to overcome by dilating. And thus, by contracting in the intervals of the shocks, they tend to produce a continuous, instead of an intermittent, flow along the vessels. If the tubes had been rigid, the jerk would have been as violent at the end of the artery as at its commencement. The muscular coat in the lower animals (rabbit, frog, etc.) helps, by its

contraction, the circulation of the blood. In man its influence in this way is very feeble. Its chief use appears to be, by actively lessening the calibre of any of the blood-vessels, to diminish at will the supply of blood to the part.

The inner and muscular coats also subserve the important use of stopping the loss of blood from a severed artery by contracting and folding inwards, so as to partly close the mouth of the vessel.

All arteries in life are kept more or less on a constant stretch by the blood current within, and it is the constant pressure they thus exercise, by the passive force of elasticity and the active force of muscular contraction, that changes the intermittent jerk into the continuous flow.

2. THE VEINS AND CAPILLARIES.

Structure of Veins.

Veins have also three coats, of the same character as arteries, but much thinner, so that when the vessel is empty its walls collapse, and it lies flat. The muscular coat between is often irregular, and sometimes the fibres are longitudinal. The outer fibrous coat is always the strongest in the veins. The inner coat of the veins is reduplicated in folds occurring at regular intervals, so as to form, when distended by any back pressure, pairs of valves, freely allowing blood to proceed towards the heart, but preventing any return. The large terminal veins at the heart (venæ cavæ), the veins of the liver, kidneys, lungs, and brain have no valves. They are, however, always found in the veins of the limbs. The veins commence in tiny twigs near the termination of the nearest

Valves.

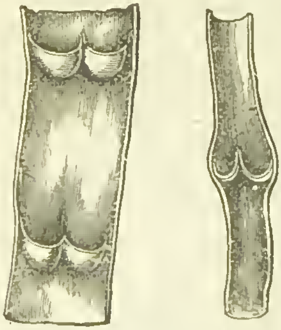


Fig. 71.—A Vein and Valves.

arteries, which twigs gradually unite into larger branches, until at length the whole stream is returned in two great vessels to the heart, each of which is of the same calibre as the aorta, through which all the blood leaves it; so that the united capacity of the veins is about double that of the arteries.

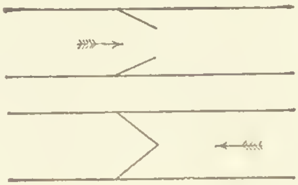


Fig. 72.—Diagram of Valves in Veins.

Discovery of Capillaries.

Until the invention of the microscope no connection was known between the end of the artery and the commencement of the vein, but this instrument revealed (to Malpighi in 1661) the existence of a network of fine vessels connecting the arteries with the

Fig. 73.—Capillaries, uniting an Artery and a Vein.

veins, so minute as to be quite invisible ($\frac{1}{3000}$ inch), at least one-fourth smaller than the faintest line visible to the naked eye, and yet so close that the point of a needle could not be inserted into any tissue without wounding one.

In the liver and lungs the spaces between the vessels are smaller than the capillaries themselves. In the brain they are much less numerous, the result being that the flow of blood through them is more rapid; the brain, owing to the extreme activity of the changes in the vein cells, requiring a greater supply of *fresh* blood than any other part. These vessels, like hairs, are therefore called "**capillaries.**" They carry the blood from the artery to the vein,

Fig. 74.—Capillaries and Body Cells.

Fig. 75.—Blood Capillary.

and it is in its passage through them that the blood nourishes the surrounding tissues.

The whole of the body may thus be regarded as consisting of groups of tiny islets, surrounded by streams of blood flowing in capillaries. These capillaries themselves lie in larger lymph channels, the fluid of which ever bathes their walls, so that they form, as it were, a stream within a stream.

Construction of the Capillaries.

Their walls are of the slenderest construction, and consist of a single layer of flat fusiform plate-like cells, very

thin, and loosely cemented together. The capillaries are large enough to allow from one to three red corpuscles to pass abreast.

Just as the arteries are constructed to prevent any escape of the blood and to regulate its flow, and the veins to assist in its movement forwards by their flexible walls and valves, so the capillaries are made to allow the freest possible interchange between the blood and the tissues, and the greatest possible change in size; the vasomotor nerves that are connected with them having the power instantaneously to close the tiny tube altogether, or to enlarge it to double its size.

Functions of the Capillaries.

The capillaries are of inconceivable numbers; those in the lungs alone, placed in a continuous line, would reach thousands of miles. The smallest are in the brain and lungs. Their united capacity is no less than 500 times that of the arteries, so that we may regard the blood as leaving the heart by a pipe one inch in diameter, and suddenly expanding at the capillaries to a tube two feet in diameter, and then contracting in the veins, when the blood reaches

Their Numbers.

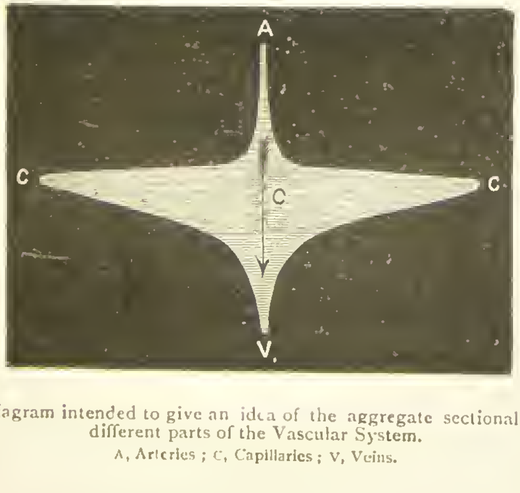


Fig. 76.—Diagram intended to give an idea of the aggregate sectional area of the different parts of the Vascular System.
A, Arteries; C, Capillaries; V, Veins.

the heart again, to two inches. The enormous increase of size in the capillaries, and the large increase of friction from the minuteness of these individual channels, greatly retards the blood flow, and destroys the force of the heart-beat. It also assists in keeping up a continuous pressure in the arteries. In the arteries the blood flows about a foot a second, in the capillaries an inch a minute, in the veins an inch a second.

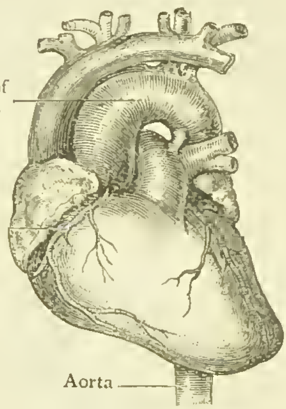


Fig. 77.—The Aorta and Arch.

The Heart.

We will now consider the structure of the heart — the living force-pump by which the blood is circulated through the body.

3. THE HEART.

Structure.

The heart is in the form of a blunt hollow cone, about the size of its owner's fist, and weighing about nine ounces, and is situated behind and somewhat to the left side of the lower half of the breast-bone. Its base is uppermost and to the right, its apex being downwards and towards the left. It consists, like the arteries and veins, of three coats: an *outer* fibrous coat called the *pericardium*, which really consists of two layers, forming a closed sac, the heart being folded up in it. The inner layer is closely adherent to the heart, and the outer layer to the connective tissue round, a small amount of fluid being between the two. The *middle* or muscular coat forms the main substance of the heart itself, and, in a muscular man, varies from a quarter of an inch to an inch in thickness: while the *inner* coat is the lining membrane of the heart.

The muscles are peculiar. The fibres are intermediate between the striped or voluntary muscles of the limbs, and the unstriped or involuntary muscles of the arteries. They have transverse stripes like the former,

Heart Muscle.

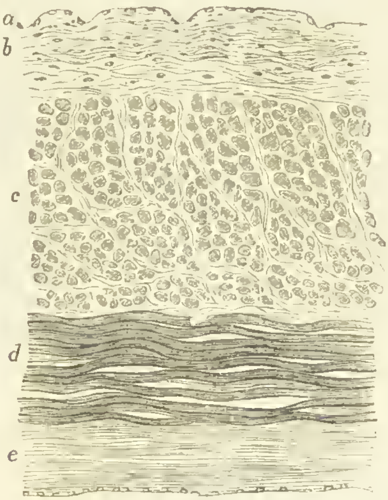


Fig. 78.—Transverse Section through the Auricle of the Heart of a Child.

a, Endothelium lining the endocardium; *b*, endocardium; *c*, muscular bundles cut transversely *d*, muscular bundles cut longitudinally; *e*, pericardial covering.

but are not under the control of the will, thus resembling the latter. They are arranged in circular, oblique, longitudinal, and (towards the apex) in spiral layers. They continue for some distance along the two large veins. The fibres that surround the upper half of the heart are distinet, and can aet separately from those round the lower half.

Inside, the heart in man is divided longitudinally into two halves, right and left; each half is divided transversely, thus making four chambers in all.

Chambers of the Heart.

In fish there are but two, in a frog three, while from the crocodile upwards, we get four. In the embryo all these stages are gone through.

The two upper chambers are called respectively the right and left *auricles*, and have very thin muscular walls;

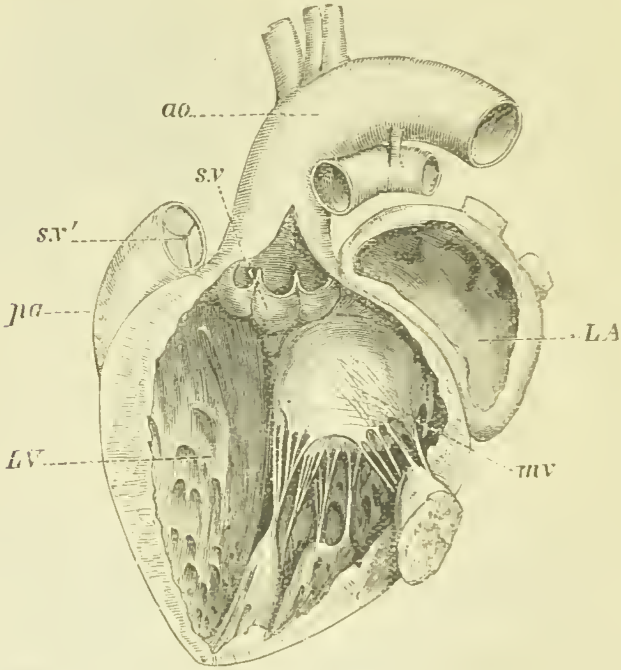


Fig. 79.—Heart with Wall of Left Auricle and Ventricle removed.
ao, Aorta; *sv*, *sv'*, semilunar valves; *pa*, pulmonary artery; *LV*, left ventricle; *LA*, left auricle; *mv*, mitral valve.

the two lower ones the right and left *ventricles*, and have much thicker walls; the left being also at least three times the strength of the right. Each chamber holds about four tablespoonfuls of blood. There is no direct communication between the right and left side of the heart after fœtal life.

Each auricle communicates with the ventricle below by a sort of large trap door in the floor, which on the right

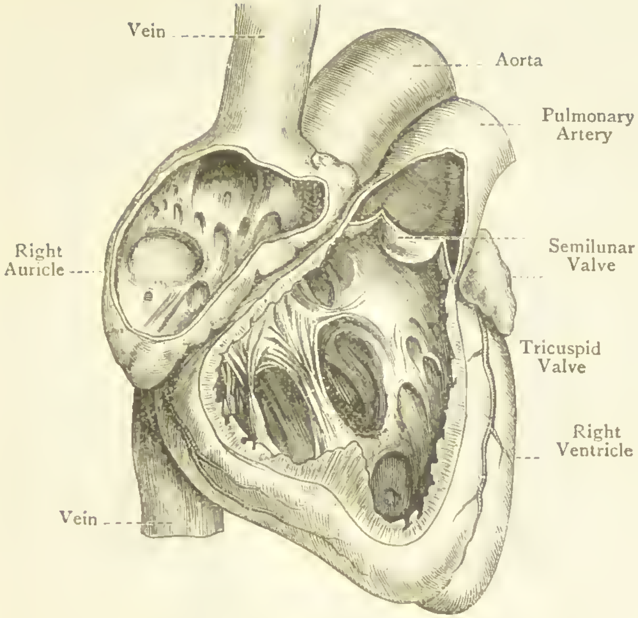


Fig. 80.—Heart with Wall of Right Auricle and Ventricle removed.

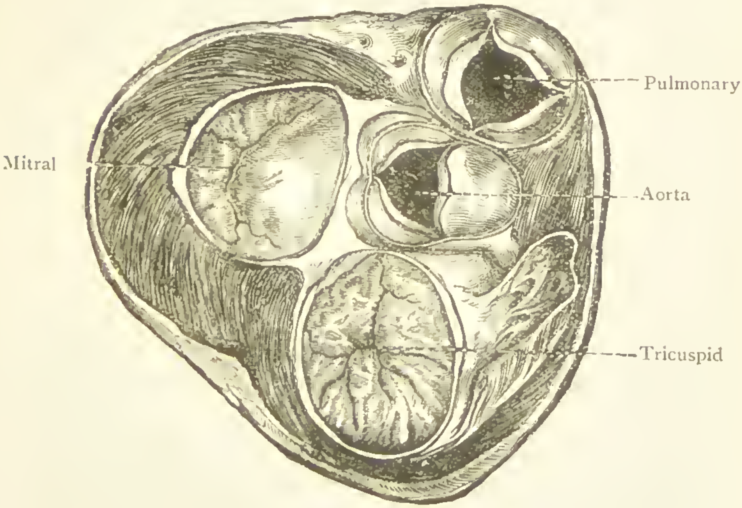


Fig. 81.—Transverse Section of Heart (from above) showing Valves.

side consists of three flaps, and is called the *tricuspid valve;* and on the left of two, and is called the *mitral valve.*

Valves.

The right auricle has, in addition to this valve, the large opening (*sinus venosus*) common to the terminal veins.

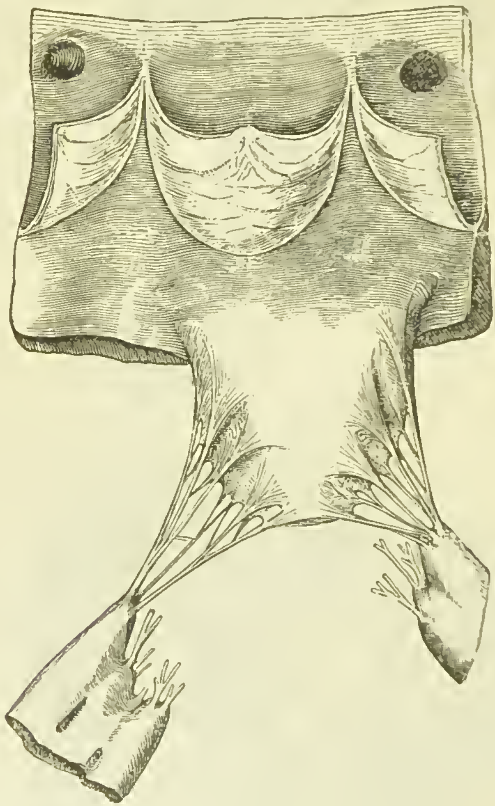


Fig. 82.—Portion of the Wall of Left Ventricle and Aorta, showing Semilunar Valves above with pockets and openings of two Coronary Arteries; and below one flap of Mitral Valve attached by Chordæ Tendineæ to the Columnæ Carneæ.

In the right ventricle is the opening of the large *pulmonary artery* that conveys the blood to the lungs to be purified, guarded by a *semilunar valve*, which has three

flaps. The left auricle has four openings for the four *pulmonary veins* that return the purified blood from the lungs to the heart; and in the left ventricle is the large opening of the *aorta*, by which the blood finally leaves, guarded by a *semilunar valve*, which has three flaps, as in the right ventricle. There are thus, in the heart, four valves with three flaps (two semilunar and one tricuspid), and one with two flaps (the mitral). The arrangement of all these valves is such that the blood can only pass in one direction, always from the venæ cavæ towards the aorta. The orifices of the valves are strengthened by strong fibrous rings, while thc flaps of the tricuspid and mitral valves are strengthened and prevented from rising too far by strong pillars (*columnæ carneæ*) and cords (*chordæ tendineæ*) fixed from the inner surface of the ventricle to their lower side.

CHAPTER X.

THE CIRCULATION.

I. GENERAL COURSE.

WE must now consider how the blood moves through the vessels we have described, and circulates through the body.

General Course of Circulation.

The blood is incessantly leaving the left side of the heart by the arteries, traversing every tissue through the capillaries, returning to the right side of the heart by the veins, and thence passing through the lungs to where it started from.

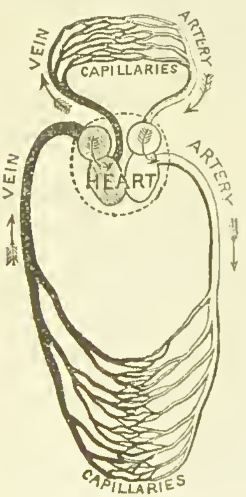


Fig. 83.—The Circulatory System.

Let us consider this incessant movement in detail.

The exhausted venous blood returns by the two venæ cavæ. Into the lower one fresh stores of albuminous and saccharine material are poured, and into the upper one the digested fat food in the chyle by the left subclavian vein.

From the Veins to the right Ventricle.

The lower vena cava also receives the blood from the renal veins, which is *the purest blood in the body.*

The venous blood, thus replenished with food but deficient in oxygen, is poured into the right auricle by the two veins, and as the tricuspid valve in the floor with its three flaps is widely open, the blood pours straight down into the ventricle below. As this fills with its

four tablespoonfuls of blood, the three flaps are floated up and gently close together. A sudden contraction (a nervous spasm) of the auricle now takes place, commencing in the muscular tissue that extends along the venæ cavæ, and forcing the rest of the blood down into the ventricle until it is fully distended. The semilunar valve of the *pulmonary artery* leading out of it, however, still remains tightly closed by the pressure of the blood on the other side, and by this time the tricuspid valve is also firmly shut by the pressure of the blood in the ventricle.

From the Right Ventricle to the Left Auricle through the Lungs.

Immediately following the contraction of the auricle a powerful contraction of the ventricle takes place. This bursts open the semilunar valve, and the blood rushes along towards the lungs. It would also burst upwards the tricuspid valve but for a two-fold safeguard. Not only are the lower sides of the flaps firmly attached by fibrous cords to the walls of the ventricle, but these cords (*chordæ tendineæ*) in many cases rise from the extremity of short muscular pillars (*columnæ carneæ*) which contract with the ventricle, and thereby keep the cords in a state of tension. Were it not for this ingenious contrivance, as the ventricle contracts the cords would naturally slacken, and allow the flaps to get everted upwards.

Safety-Valve Action.

Nearly every drop of blood is squeezed out of the right ventricle into the lungs by this contraction. In case, however, of there being any destruction or disease in the lungs that absolutely prevents the passage of the normal quantity of blood, a little leakage is allowed through the tricuspid valve into the auricle above, which is called the "safety-valve" action of the heart.

The blood leaves the lungs again by *four pulmonary veins*, which, now the heart is flaccid and at rest again, pour the oxygenated blood into the left auricle, whence it

drops through the open *mitral valve* down into the left ventricle, the semilunar valve of which is kept firmly closed by the pressure of the blood on the other side of it, in the aorta.

From the Left Auricle to the Venæ Cavæ round the Body.

The process on the right side is now repeated, the flaps float up, the auricle contracts simultaneously with the right side, then the ventricle contracts simultaneously with the right side, but with much greater force—seeing its walls are three times as thick; the mitral flaps are tightly jammed together, the semilunar flaps burst open, and the blood rushes along the aorta on its course; to return in about half a minute back again by the veins to the right heart.

Speed of the Blood.

In the arteries the blood rushes along at the rate of about a *foot a second*; in the capillaries at an *inch a minute*, and in the veins about an *inch a second*. If the arteries were rigid like glass tubes the blood would flow over 200 feet a second. The elasticity retards the speed.

Walls of the Heart.

We see now why the walls of the ventricles are thicker than the auricles, and why the left ventricle is the thickest of all. The auricles in forcing the blood into the ventricles have no resistance to overcome, the ventricles being empty; whereas the ventricles have to overcome the pressure of the columns of blood in the pulmonary artery and the aorta; and inasmuch as the body circulation contains much more blood than the pulmonary, the pressure to be overcome is far greater in the left ventricle than the right.

2. THE PULSE.

The first effect of the rush of blood into the aorta is to transmit a shock to the entire mass of blood in the body. If the blood-vessels were rigid tubes, an amount of blood

would be ejected at each beat into the right heart equal to that which leaves the left, but they are elastic, and the great arteries especially so. The force of the heart is thus expended—first, in forcing the blood into the artery and producing a shock; and, secondly, in distending the artery sufficiently to receive the blood.

Cause of the Pulse.

When the aortic valve is closed, this part of the force, stored up as elastic tension, comes into play and drives part of the fluid along in its turn, distending the smaller arteries. This jerky movement of the blood can be felt

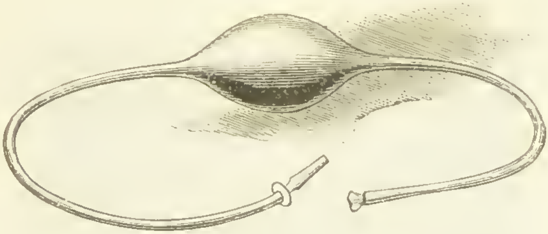


Fig. 84.—Syringe illustrating Action of Heart and Valves.

in the larger arteries, as in one at the wrist, and is called the pulse. What the finger feels is not the first shock caused by the heart, but the subsequent wave of blood driven forward by the contraction of the distended aorta. Hence the pulse is always after the heart's beat.

In very feeble people a second impulse can be felt, which is the recoil wave caused by the closure of the valve.

There is no pulse in the capillaries or veins. *First*, because the united calibre of these is so much larger: but if this were all, the pulse would reappear as they united towards the heart. But, *secondly*, it is on account of the immense number, and minute size of, and the great resistance offered by, the capillaries; so that the blood can never pass through them fast

No Pulse in the Veins.

enough, and the arteries are thus always distended and over-full. It will be found that under these conditions an elastic tube converts an intermittent into a continuous flow.

If a Higginson's syringe pumps water through a glass tube, however small an outlet there may be, the jet will always be in jerks, but if the delivery tube be elastic, and the nozzle fine, it will be continuous. Part of the force of the pump in this case being expended, as in the arteries, in distending the tube, and the outlet, as in the capillaries, being too small for the water, the elastic recoil comes into play between the jerks, and keeps the pressure at the outlet continuous (Fig. 84).

The pulse rate varies from 140 at birth to 75 in adult life. It beats about 4½ times to each respiration.

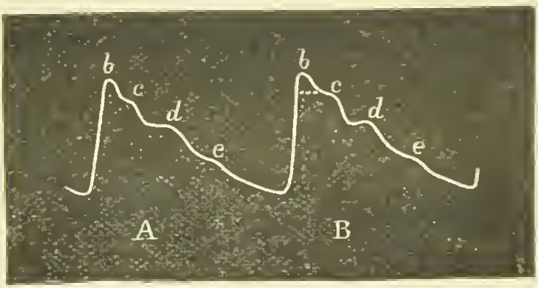


Fig. 85.—Type of Normal Pulse.
b, Primary wave; *d*, dichrotic wave; *c* and *e*, secondary waves.

Quality of the Pulse.

It may vary in four ways: in *speed*, or the rapidity of the jerks; in *strength*, or in their force; in *tension*, or stretching of the artery; and in *size*, or volume of the stream.

In certain cases of extreme weakness, as we have said, the recoil wave, from the shutting of the aortic valve, can be felt, and is called a *dichrotic* wave.

The Sphygmograph.

The movements of the pulse at the wrist, or the beat of the heart on the chest wall, can be registered far more accurately mechanically than by the finger—by the *sphygmograph* and *cardiograph* respectively.

These instruments consist essentially of a fine lever placed on the beat and connected with a sheet of smoked paper on which its movements are traced.

3. OTHER DETAILS OF CIRCULATION.

The sounds of the heart, as heard when the ear is placed against the chest wall, are two in number; the first long and dull is like *lŭbb*, the second short and sharp like *dŭp*. The first is caused partly by the closure of the tricuspid and mitral valves, and partly by the sound of the contracting muscle; the second sound by the slamming of the aorta valve, for it is found if the flaps be hooked back the sound ceases.

Heart Sounds.

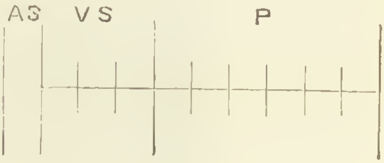


Fig. 86.—Diagram of Heart Beat.
AS, Auricular Systole, $\frac{1}{10}$ sec.; VS, Ventricular Systole, $\frac{3}{10}$ sec.; P, Pause — $\frac{6}{10}$ sec.

The movement of the heart is shown by a beat occurring on the chest wall in the fifth interspace, two inches below and one inch to the inner side of the left nipple. It is caused by the spiral arrangement of the muscle fibres at the apex, causing it to turn sharply against the chest wall at each beat.

Beat of the Heart.

The force of the beat of the left ventricle is double that of the right. The whole force exerted by the heart is equal to 120 tons lifted one foot high, or the heart's own weight 20,000 feet every hour.

The greatest height an active man can raise himself is 1,000 feet an hour; a locomotive can raise itself nearly 3,000.

There is an idea that the heart is more incessantly at work than other organs. Such is not the case, but the periods of rest alternate much more rapidly. All working parts of the body have their intervals of rest: the brain when

we sleep; the stomach, eyelids, diaphragm, etc., at shorter intervals.

Systole and Diastole.

If the whole circle of the heart's action be completed in one second, nearly half of this is rest, and may be represented as in Fig. 86.

The contraction of the heart is called the **systole**, the rest the **diastole**.

The movements of the heart are mainly caused by three

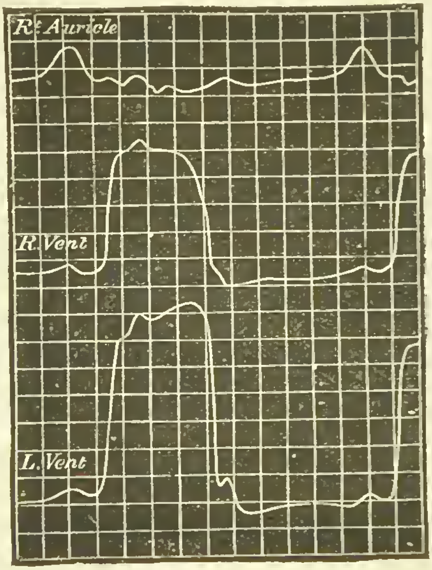


Fig. 87.—Curves Drawn on a Moving Surface by Three Levers.

sets of ganglia in the heart itself. With proper care a heart can therefore beat when out of the body altogether, and even when cut in three pieces, each of which includes one of these ganglia or nerve centres.

Ganglia of the Heart.

A frog's heart will beat for days if fed with blood, for twelve hours with oxygen, for three hours with air, for half an hour *in vacuo*, while CO_2 stops it at once.

The rapidity and force of the heart's movements are regulated from outside by two nerves—the *pneumogastric*, from the brain, which slows or retards it; and the *sympathetic*, which accelerates it. The blood pressure in the heart is regulated through *the depressor nerve*, a branch of the vagus, which acts by suddenly dilating the large vessels in the abdomen to lessen the heart pressure, or by constricting them to raise it.

Regulation of the Heart.

If the former nerve be irritated artificially by pressure or poison, or by disease, the heart's beat becomes very intermittent. If, on the other hand, the sympathetic be stimulated by pressure, as in indigestion or by poison, or by alcohol, or by mental influence, or joy, etc., the heart's beat is enormously quickened, and often goes so fast that it is made to palpitate.

The general system of nerves, called the vaso-motor system, that controls the calibre and tone of the blood-vessels, also is connected with the heart, so that the tension of the arteries and the force of the heart's beats are regulated with each other. The heart itself is nourished with blood by two vessels that arise from the aorta just behind the valve, and are called the *coronary arteries*, the vein from them returning to the right auricle, where its mouth is guarded by a little valve. This is the shortest course the blood can take to form a complete circuit (Fig. 82).

Vaso-motor System.

All blood must pass through two sets of capillaries, one in the part it supplies, and the other in the lungs. In one direction, however, it has to pass through three. All the blood from the internal organs is collected into the vessel called the *portal vein*, and enters the liver here; it breaks up into capillaries, and is collected again by the hepatic vein and enters the venæ cavæ. This is called the *portal circulation*.

The Portal Circulation.

Three other parts of the circulation are peculiar :—The *respiratory*, where the arteries are straight and do not anastomose, and the veins have no valves ; the *cerebral*, where the arteries anastomose freely and the blood returns in rigid sinuses instead of veins ; and the *erectile*, where the blood is retained at will in large venous spaces.

Proof of the Circulation.

The proof of the circulation of the blood mainly consists in the following points :—

(1) The arrangement of the valves of the heart, all of which allow movement only in one and the same direction ; (2) the opposite results of pressure on or tying a vein, as compared with an artery : the one swelling up on the distal side or that furthest from the heart, the other on the proximal or that nearest to the heart ; (3) the presence of valves in the veins, only allowing the blood to flow towards the heart ; (4) the introduction of certain substances into the blood which are proved to travel round ; and (5) the direct observation of the blood current in life as seen in the web of a frog's foot.

Finally, we have to consider what other forces aid circulation beside the heart's impulse, which in itself even under favourable circumstances would hardly be quite sufficient.

Aids to Circulation.

1. We have already seen how force is stored up, and passed on by the elasticity of the arteries.

2. In the veins the valves and the collapsible walls, which are squeezed at every contraction of the muscles in which they are imbedded, help the blood up to the heart.

3. A still greater force, however, is that of respiration, which, by creating a vacuum in the chest, relieves the vessels of all pressure there, and, as it were, sucks the blood towards the heart. As the veins enter the chest the force of the heart's beat has got so feeble that this is the principal power left. Expiration, of course, has a contrary effect, and when prolonged, as in coughing, stops the venous flow, as may be seen in the swollen veins of the neck.

The course of the fœtal circulation is described in the last chapter of this book.

4. THE VASCULAR GLANDS.

As indirectly connected with the vascular system, we may here consider the vascular glands, which include the spleen, the thyroid, and the thymus glands in the thorax; the suprarenal capsules above the kidneys; the pineal gland and pituitary body in the brain; and the carotid and coccygeal glands. Vascular Glands.

Fig. 88.—Malpighian Bodies on an Arterial Twig (from the Spleen of a Pig).

The spleen is about the size and shape of the palm of the owner's hand, and is situated beneath the ninth, tenth, and eleventh ribs in the left side, beneath the diaphragm. Its convex side is outwards, The Spleen.

and its concave side is in close proximity to the tail of the pancreas. It is of a deep red colour, and full of blood. The vessels enter and leave on the inner concave side. The spleen is covered with the serous coat of the peritoneum, and then with a fibrous capsule which sends trabeculæ inwards that support the spleen pulp of which the organ is composed.

This **spleen pulp** is formed of round nucleated cells,

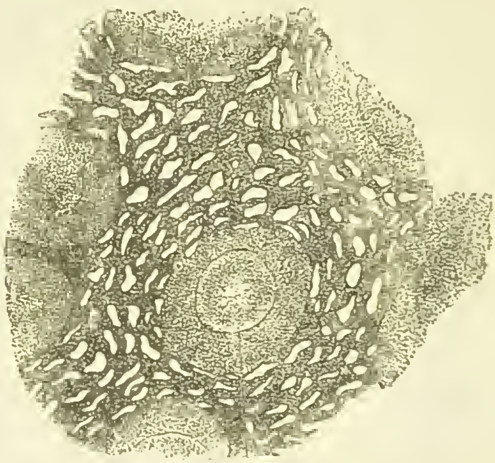


Fig. 89.—Section of the Spleen of a Rabbit, showing Spleen Pulp.

held in the meshes of large branching epithelial cells, which form a sort of adenoid tissue. There are also many cells like red blood corpuscles. The splenic artery breaks up into arterioles that *do not anastomose*, so that each branch is *terminal* (this explains how the blocking of one produces infarction of the spleen); and also into a series of spaces into which the splenic corpuscles can freely enter.

There are various views as to the capillary system of the spleen. but all are agreed that it is freely open in many places, in a manner

peculiar to the organ, for the entrance of the splenic corpuscles into the blood.

The so-called Malpighian corpuscles of the spleen must not be confounded with structures of a similar name in the kidney, and are simply outgrowths on the sheath of the smaller arteries of masses of adenoid tissue, containing lymph corpuscles surrounded with capillaries. They are about 70,000 in number, each the size of a millet seed (Fig. 88).

It appears probable that the spleen performs at least two great functions :—

1. *The elaborating and storing of peptones and albuminous food.*

Its Functions.

It is found that it increases in size after digestion from the store of albuminous plasma it contains, and subsequently slowly decreases; this and the constant pressure of uric acid points to some definite nitrogenous metabolism.

2. *The formation and breaking up of blood corpuscles.*

It seems to introduce numbers of colourless and red corpuscles into the blood, as well as to receive worn-out corpuscles, which form red masses that eventually disappear.

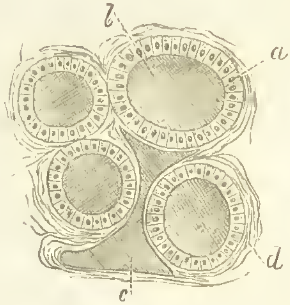


Fig. 90.—From a Section through the Thyroid Gland of Dog.

a, The epithelium lining the vesicles; *b*, the "colloid" contents of the vesicles; *c*, a lymphatic filled with the same material as the vesicles; *d*, the fibrous tissue between the gland vesicles.

It probably has other functions, as a blood reservoir, etc.

It can be enlarged and contracted by some drugs as well as by disease (ague).

The Thyroid.

The **thyroid glands** consist of two lobes, one on each side of the trachea connected by an isthmus. Each is covered with a capsule with strong trabeculæ that enclose the *vesicles*, which are sacs bound with a single layer of cubical cells, and containing a colloid material like gum. The gland is very vascular. This

colloid product is carried off by the lymphatics into the blood. Nothing further is definitely known as to the functions of the gland. It is enlarged in goitre.

The Thymus.

The **thymus gland** is largest shortly after birth, and at puberty has almost disappeared. It is an inch long when largest, and is situated behind the sternum. Like the other glands, it has a fibrous capsule

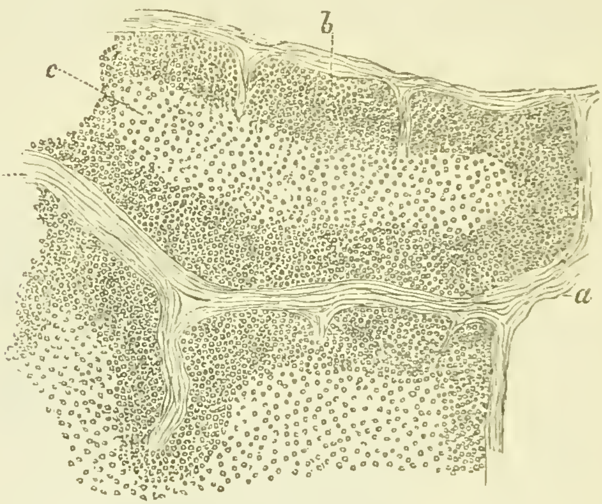


Fig. 91.—Section through the Thymus Gland of a Fœtus.
a, Fibrous tissue between the follicles; *b*, the cortical portion of the follicles; *c*, the medullary portion.

with trabeculæ, containing small *follicles*, consisting of adenoid tissue, the middle of which has fewer corpuscles than the denser cortex. They contain giant cells with many nuclei, and concentric corpuscles of Hassall, masses of flattened cells surrounding a nucleated centre. In early life the thymus may help to produce the blood corpuscles.

The Suprarenal Capsules.

The **suprarenal capsules** are two small bodies like cocked hats, perched on the top of the kidneys. Each is surrounded by connective tissue sending fine septa inside, while the gland itself is divided into

cortical and medullary portions. The *cortical* portion has a dense horizontal stratum externally, and vertical layers of cylindrical masses internally, separated by the

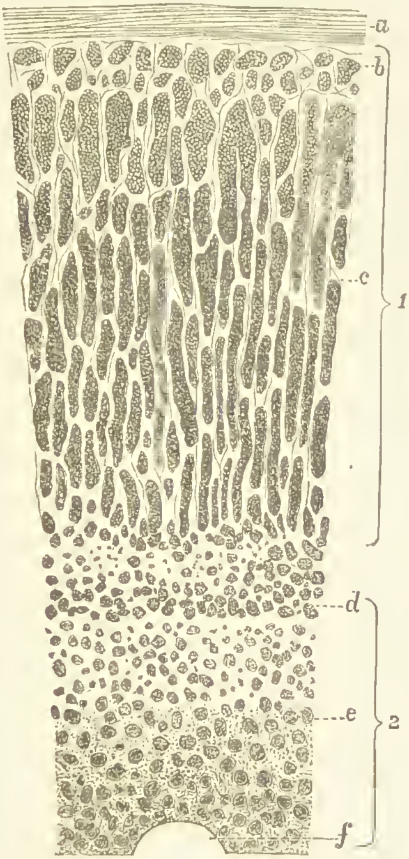


Fig. 92.—From a Vertical Section through the Suprarenal Capsule of Man. 1, Cortical substance; 2, medullary part; *a*, outer capsule; *b*, zona glomerulosa; *c*, zona fasciculata; *d*, zona reticularis; *e*, medulla; *f*, a large vein. (Elberth, in Stricker's Manual.)

connective tissue, and both containing nucleated masses of protoplasm of different shapes, which apparently are not formed into regular cells.

The *medullary* portion is a loose network of adenoid tissue with irregular shaped cells in its network. Of the functions of the glands nothing is known.

They are often found altered in Addison's disease.

The **pituitary body** is a small grey mass consisting of two lobes in the forepart of the brain. Of its functions nothing is known.

The **coccygeal** and **carotid glands** are two small plexi of arteries and small cells in capsules situated at the top of the coccyx and at the bifurcation of the carotid in the neck. Their use is unknown.

CHAPTER XI.

BODY HEAT.

I. PRODUCTION OF HEAT.

THE **Heat** of the body consists in the combustion of O with the production of CO_2 and water. It is a form of energy, and is produced by the vibration of the corporeal atoms. The ultimate *source* of it is the food and oxygen taken into the body, and the *cause* of it is the metabolism or vital changes of the body, and the *amount* of it depends on the amount of these changes. The repair, building up, or *anabolism* of the tissue is, however, believed rather to absorb heat than to evolve it. It is in the decay, oxidation, or *katabolism* of the tissues that heat is principally evolved. It is found, indeed, by direct experiment that the amount of C and H that unite in the body in twenty-four hours with O is sufficient to maintain the body temperature for a day.

Source of Heat.

The energy stored in the food of the body could be truly described as latent heat were all of it used in the production of heat. Nevertheless, though some of it produces mechanical and electrical energy, it is convenient to measure its potential forces under the head of heat-units. A heat unit, as we have already seen, is 1 gramme of water raised 1 °C., and corresponds in mechanical energy with 425·5 work units (a work unit being 1 gramme raised 1 metre high). The amount of heat units in any food is found by burning it in a closed chamber surrounded with a fixed quantity of water, which in its turn is in a chamber,

Heat Units.

isolated by non-conducting substances and cold water, from any external heat. The heat evolved passes by means of a coiled lead tube through the water, and the increase of its temperature, ascertained by delicate thermometers, multiplied with the volume of water, readily gives the number of heat units. In like manner ice can be used, and the amount melted calculated. The one is a water and the other an ice *calorimeter*.

A living animal can be placed inside instead of food, and the heat it gives off passing through the water in like manner shows the number of heat units it evolves.

Heat of Foods.

It is thus found that 100 parts of albumen contain as many heat units as 52 of fat, 114 starch, or 130 sugar. The reason that fat gives so much more heat than starch or sugar is that in the latter the H and O are in the proportions to form water, so that *the C alone is burnt;* whereas in fat there is always a great excess of H, so that both C and H oxidise and are sources of heat. Some heat no doubt enters the body through hot drinks.

Heat Centres.

The places where most heat is produced are the muscles, secreting glands and organs, and brain. The muscles form about one-half of the body, and the bones nearly the other half. The latter produce but little heat, whereas the former are the greatest *thermogenic* centres in the body. Muscle work forms about $\frac{1}{5}$ of all the work done in the body, and of it $\frac{9}{10}$ is produced in heat units, and only $\frac{1}{10}$ in mechanical energy. The heart must be included with the muscles as a thermogenic centre.

The secreting glands, such as the liver, produce heat. With salivary glands the blood leaving them is a degree hotter when they act than when they are passive. In the liver of the dog the temperature in the hepatic vein is often 105°.

The brain, by its active metabolism, is also a source of heat.

Other small sources of heat are the concussion of joints, the friction of muscles, blood, etc., and electric currents, the formation of salts and other chemical changes.

2. REGULATION OF HEAT.

Warm and cold-blooded animals have lately been called *homoiothermal*, or of uniform heat; and *poikilothermal*, or of varying heat, because the real difference between them is that the blood in a warm-blooded animal remains the same notwithstanding variations in surrounding temperature; while the blood in the cold-blooded animal varies with the surrounding medium.

Warm and Cold-blooded Animals.

Of warm-blooded animals (mammals and birds), man has a temperature of 99° F. (98·6 in the armpit); the dog 102° F.; the cat 103° F.; the mouse 106 F°.; the average temperature of the mammalia being 101° F. In birds the average temperature is 107° F., that of linnets rising to 111° F. Amongst cold-blooded animals many vary but slightly with the surrounding temperature. Snakes average 82° F.; in cold weather they are hotter, and in hot, colder than the air. Fish are often one or two degrees warmer than the water, the tunny fish being as much as seven degrees F. The frog is generally about half a degree warmer than the water.

In warm-blooded animals the metabolism and the consumption of oxygen *increase* in cold weather and decrease in hot; whereas in cold-blooded animals the metabolism and the consumption of oxygen *decrease* in cold weather and increase in hot.

This shows there is some regulating or *thermotaxic* centre that governs the production or *thermogenesis* of heat. That this centre is nervous is shown by the fact that after poisoning with curari this regulating power is lost, and the warm-blooded animal behaves like a cold-blooded one.

Regulating Heat Centres.

Though the blood can complete the circuit of the body in twenty-three seconds, nevertheless the temperature varies as follows :—

Heat at Different Parts.

On the skin from 72·6° F. at the top of nose and ear to 96° F. in middle of upper arm, and 98·6° F. in closed axilla, the average being about 92 to 94° F. The skin is observed to be warmer over muscle than bone.

In the rectum the temperature is 100° F., the blood is 102° F., the brain 104° F., the liver and heart 106° F.

Conditions Affecting Temperature.

Muscles and glands increase in heat one degree during action, and the brain about half a degree. The principal conditions affecting the mean temperature of the body are age, sex, period of day, exercise, season, food, poisons and disease.

Age.—In the newly born the temperature is one degree above normal, also in the very aged ; but in these the governing (thermotaxic) centres being feeble, exposure soon lowers it to a dangerous degree.

Infants and children are very subject to feverish attacks, owing to the activity of their metabolism and the imperfect development of the thermotaxic centre. From 28 to 65, this centre being fully developed, the temperature of the body is kept more uniform, while in old age variations from slight causes again occur readily.

Sex.—In woman the temperature is higher than in man.

Period.—The temperature rises during the day and falls during the night, being highest at 6 p.m. (99·8° F.) and lowest at 2 a.m. (97·6° F.).

Exercise.—Active exercise will increase the temperature from 1° to 2° F.

Season.—In summer the temperature is three degrees higher than in winter. Climates varying 100° F. have no effect on body temperature.

Food.—There is a very slight rise after food. A fall of one degree after taking cold alcohol, and a temporary rise of ·5° after taking hot alcohol.

Poisons.—Alcohol, quinine, aconite, etc., decrease temperature. Strychnine raises it.

In diseases the temperature varies from 77° F. in Asiatic cholera to 107° F. in pneumonia. After death the temperature rises for a short time, especially at the onset of rigor mortis.

Cause of loss of Heat.

The heat of the body may be regulated by altering the amount lost, or the amount produced. In the body this is done in various ways, the process being governed by a nervous centre. Body heat is diminished by the skin, lungs, urine, cold food, cold alcohol, and air. By the skin about 75 per cent. is lost; by the lungs 20 per cent.; by urine, etc., 3 per cent.; and about 2 per cent. in other ways.

Action of the Skin.

Heat is *lost* from the skin by conduction, radiation, and evaporation. Besides the central thermotaxic power, the skin has a self-regulating power by reflex action. A hot atmosphere acts on the sensory nerves, and by the vaso-motor nerves dilates the surface capillaries, and reduces the heat by evaporation. A cold atmosphere, *vice-versâ*, closes the capillaries and retains the heat in the body. Thus external heat and cold defeat their own ends.

There appears in the action of the skin to be a balance between radiation and evaporation that tends to assimilate the loss in winter and summer. In cold weather much heat is lost by radiation, little by evaporation, the capillaries being contracted; in hot weather much by evaporation and little by radiation, the temperature being so high.

The loss of heat from the skin can be largely regulated by clothing; wool, being a bad conductor and hygroscopic, is obviously the best covering for the skin.

A naked man is said to be unable to maintain his normal heat when the temperature is 81° F.

The loss of heat by the lungs is fairly constant, they having no power of reflex action like the skin. The loss does not, moreover, vary with the surrounding temperature, and but little with exercise.

The *production* of heat can be regulated by food, exercise, and nervous influence. Amongst foods, fat, as we have seen, gives the most heat. In paralysis the part loses heat. In nervous excitement heat is increased, in nervous depression it is diminished. In exercise the increased heat is largely counterbalanced by the increased loss.

The shivering in cold helps to warm the body.

It is calculated that a man produces nearly two heat units per minute.

The Three Centres.

We have already spoken of a thermotaxic centre. This probably controls the *thermogenic* (or heat-producing) and *thermolytic* (or heat-losing) centres. We have seen that the thermotaxic centre is produced last, and it also fails first in disease (hence pyrexia, etc.). The general action (like that of the respiratory centre) is probably partly reflex and partly automatic. The centre is believed to be situated above the medulla. Nothing is known of the details of the action of these centres.

Death from Heat.

Great extremes of *dry* heat can be borne for a short time owing to the power of evaporation possessed by the skin; thus 260° has been borne for 8 minutes; while Chabert, the fire king, entered an oven at 500° F. At the same time, if the heat is moist, evaporation is prevented, the air being already saturated, and 112° F. cannot be endured.

Death from too great heat appears to arise from too rapid and exhaustive metabolism; that from cold from too slow and diminished metabolism, death in this case coming on with torpor and sleep.

CHAPTER XII.

RESPIRATION.

I. INTRODUCTION.

WE have already considered the reception, digestion, circulation, and assimilation of the solid and liquid food of the body by means of the digestive system and the blood, and we have now to see how the gaseous or aërial food of the body (*oxygen*) is appropriated.

Introduction.

As, however, we have seen that, just as the foods of the body consist of solids, liquids, and a gas, so the waste products of the body consist of all three, we may conveniently consider here not only the reception of oxygen, but the excretion of the waste gas—carbonic acid. The double process is called *respiration*, and is carried on mainly by the lungs, to a small extent also by the skin.

These perform what may be called **external respiration**, or the reception of oxygen and excretion of carbonic acid **by the blood**. We must, however, clearly understand that there is in addition another **internal respiration** of no less importance carried on all over the body, not by any particular organ, but by the vital power inherent in each body cell, by which oxygen is received and carbonic acid excreted, not by the blood but **by the cells** from and into the blood.

External and Interna Respiration.

External respiration concerns, therefore, the exchange of

gases between the blood and the air; internal respiration, the exchange between the body cells of the tissues and the blood.

Animal and Vegetable Respiration.

The process of respiration in the animal kingdom is the reverse of that in the vegetable. These breathe in CO_2, absorb the carbon and expire oxygen; animals inspire oxygen and expire CO_2.

Principles of a Lung.

In all vertebrate animals the essential principles of a lung are seen, and these consist of *a thin membrane with blood on one side and air on the other.*

This principle can be illustrated by a moist bladder containing blood. If this be plunged in a jar of oxygen it will absorb oxygen through the membrane and become very bright; if plunged into a jar of carbonic acid it will absorb the gas and become dark or venous.

Changes in Colour of Blood.

Blood, as we have seen, if deficient in oxygen and full of CO_2 is dark *purple* or *venous*: if freed from the CO_2 and charged with oxygen, it is bright *scarlet* or *arterial.* Now, blood going to the lungs by the pulmonary artery is dark, and returning from the lungs by the pulmonary vein is bright red, so the change must have taken place in the pulmonary capillaries that connect the two.

These capillaries are spread like a network outside a thin membrane which contains air on the other side.. The gills of a fish that absorbs the air that is dissolved in the water are constructed on exactly the same principle. The air and water circulate on one side of the membranes and the blood on the other. It must of course be understood that no manufacture of gas goes on in the lungs, but simply the interchange of gases.

We will then proceed first of all to consider the mechanical construction of the apparatus, and secondly the work it does.

2. GENERAL CONSTRUCTION OF THE LUNGS.

The **lungs** are contained in the upper half of the trunk or thorax.

The Lungs Generally.

Comparing the trunk to a boiler, and the lower half being that which contains the fuel and ashes, we may consider this upper half as containing the steam, or the oxygenated blood that drives the engine.

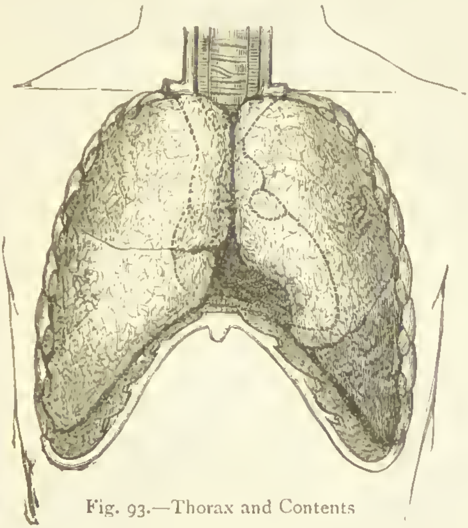


Fig. 93.—Thorax and Contents

The Thorax.

This **thorax** is in the form of a blunt cone, and is a completely closed cavity, save for an opening in the windpipe.

The thorax has a movable muscular floor called the *diaphragm*. It contains the lungs, and the heart, and great vessels. The lungs rise in the neck a little more than an inch above the collar bone, and descend down to the lower margin of the sixth rib in front and the eleventh behind.

The Windpipe.

The **trachea** or **windpipe** is a large tube that opens into the throat or pharynx behind the tongue. It has a cover, called the epiglottis, hinged to the back of the tongue in such a manner that whenever

this organ is retracted (as in swallowing food) it closes the epiglottis tightly down over the tube.

The upper four inches of the tube is much enlarged into a sort of box which forms the organ of the voice, and is called the *larynx*, of which we will speak more particularly in another chapter. From the bottom of the

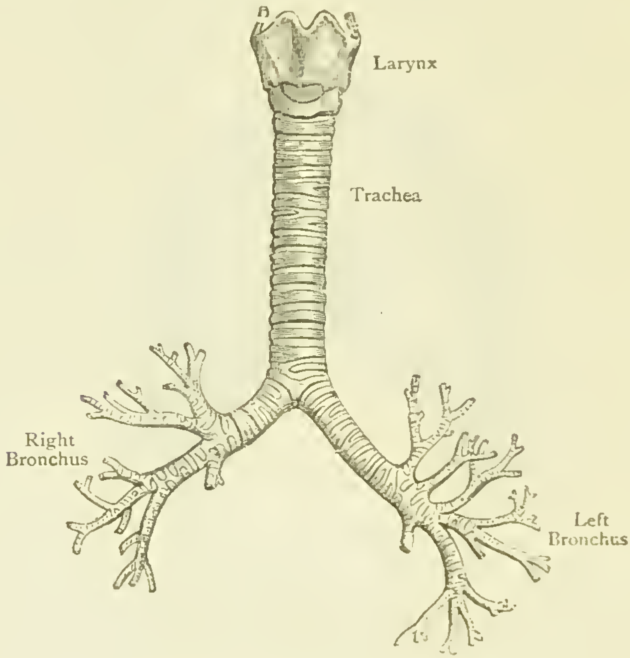


Fig. 94.—Larynx, Trachea, and Bronchi.

larynx the windpipe proper extends a distance of four and a half inches. It then divides into two large tubes called *bronchi*, right and left, which enter their respective lungs.

Description of Lungs.

The lungs are spongy, elastic, but apparently solid bodies that fill the thorax, with the exception of the space taken up by the heart and large vessels. They are not, however, really solid, but filled with air contained in innumerable microscopic

cells. The right lung is partly divided into three large *lobes*, the left into two. Each lobe is composed of thousands of *lobules* bound together by connective tissue, and each lobule is *a complete lung in miniature.*

Between the lungs and the inner surface of the ribs are the two layers of closed and empty bags, called the *pleuræ*—right and left—which we will describe shortly. The Pleuræ.

We have said that the windpipe opens by the larynx

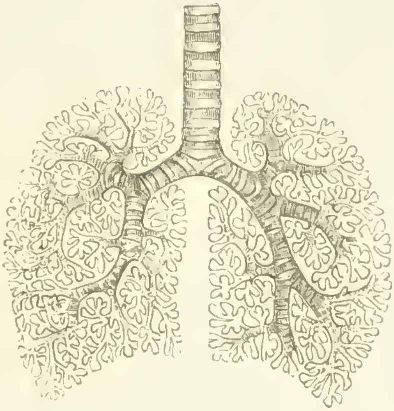


Fig. 95.—Lungs and Bronchi

into the throat, and thence into the mouth. We must also point out that it opens no less freely into the nose by means of the large posterior nares, and that there is this important difference between the two: that we can close the mouth passage at will, but we have no power to close the nose passage.

The **epiglottis** alone of all the cartilages of the air tubes is composed of yellow elastic fibre cartilage. It is covered on both sides with a layer of squamous epithelium which contains the orifices of numerous mucous glands. It is well supplied Structure of Trachea.

with lymphatics, and contains on its posterior surface a few taste goblets, like those that are found in the tongue. Passing by the larynx for the present, we find the true windpipe or trachea below consists of a tube an inch in diameter,

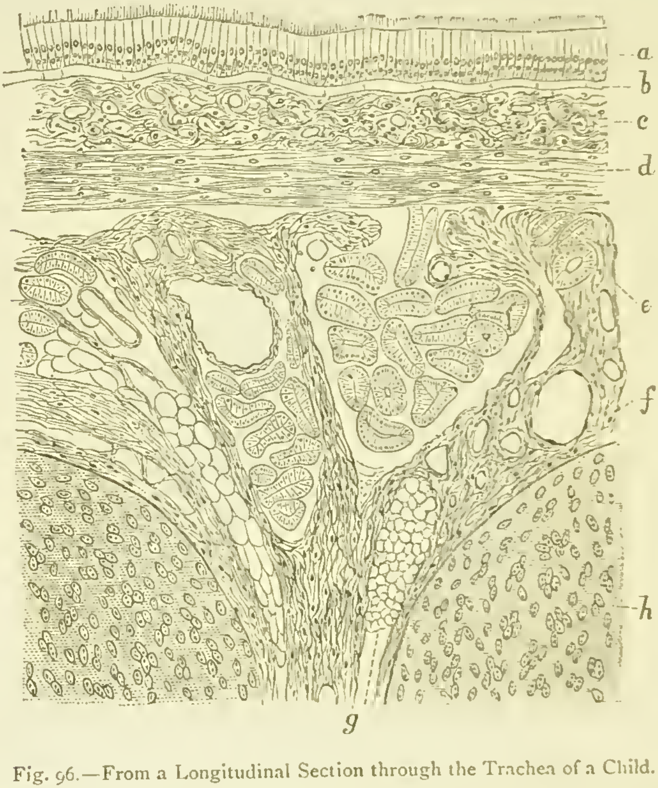


Fig. 96.—From a Longitudinal Section through the Trachea of a Child.

a, The stratified columnar ciliated epithelium of the internal free surface; *b*, the basement membrane; *c*, the mucosa; *d*, the networks of longitudinal elastic fibres; the oval nuclei between them indicate connective tissue corpuscles; *e*, the submucous tissue containing mucous glands; *f*, large blood-vessels; *g*, fat cells; *h*, hyaline cartilage of the tracheal rings.

made of fibro-elastic membrane, kept always open by 16 C-springs or incomplete rings, made of hyaline cartilages. The space between the two ends of the C, which is always directed backwards, is filled up by smooth muscle; and each

muscle is attached at each end to the ring by an elastic tendon, the space between each ring being also filled up at the back by muscle. The object of this is to prevent any pressure being put on the œsophagus, which lies immediately behind. Externally the trachea consists of fibrous tissue with numerous longitudinal muscle and elastic fibres.

Structure of the Bronchi.

The two **bronchi** right and left commence opposite the third dorsal vertebra and run into each lung; the right being the shorter and more horizontal. The incomplete cartilage rings are continued along them, but the open part of the ring is now no longer turned to the back, but to all parts of the tube. These bronchi enter each lung together with the blood-vessels and nerves, at what is called its root. In the lung they divide and subdivide very rapidly, still preserving the same character of open tubes, the rings, however, gradually becoming mere flakes of cartilage, while the transverse bands of muscle become a complete coat of circular smooth fibres, until at last each tiny **bronchiole** enters its lobule. At this stage, when the tubes are not $\frac{1}{40}$ inch in diameter, the cartilage finally ceases, and nothing is left but a tough membrane with circular smooth muscle fibres round, covered internally with longitudinal elastic fibres.

The Lining of the Bronchi.

The **mucous membrane** lining the whole of the tract may be divided into at least *four* layers. The innermost, commencing from the base of the epiglottis and extending to the bronchioles of $\frac{1}{40}$ inch in diameter, consists of a layer of ciliated columnar epithelium, which waves always in an upward direction; beneath this a layer of flattened cells (Delme's), then a clear, well-defined basement membrane. Beneath this is the fourth layer of areolar and adenoid tissue. Then we get a submucous coat, connecting this with the outer layers of the tube, consisting of loose tissue full of nerves, lymphatics, blood-vessels, and glands.

Numerous small mucous racemose glands open on to the internal surface, secreting a clear mucus.

Within the **lobule** the construction of the tube changes.

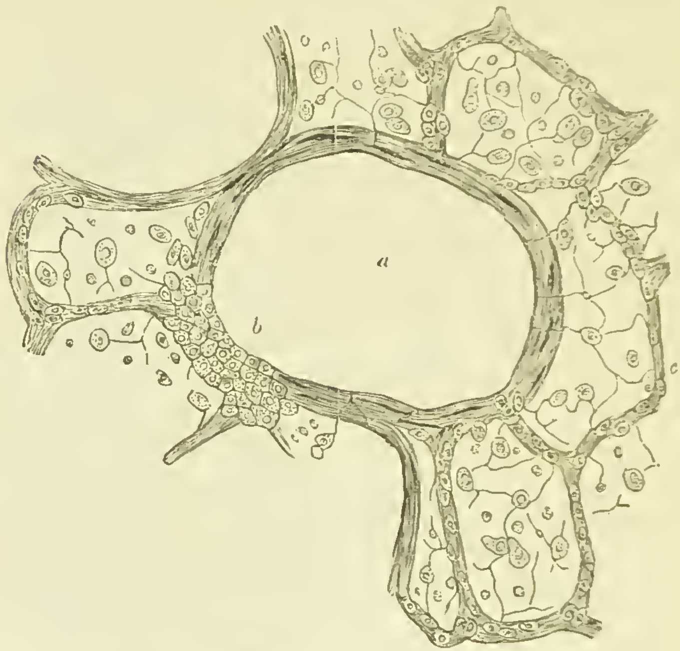


Fig. 97.—From a Section through the Lung of Cat, stained with Nitrate of Silver.

a, An infundibulum or alveolar duct in cross section; *b*, groups of polyhedral cells lining one part of the infundibulum, the rest being lined with flattened transparent epithelial scales; *c*, the alveoli lined with flattened epithelial scales; here and there between them is seen a polyhedral granular epithelial cell.

Structure of a Lobule.

The muscular fibres cease, the ciliated epithelium first gets short and cubical, and is then gradually replaced by a single layer of squamous epithelium, and the tube consists beside only of a very fine membrane covered by a few longitudinal elastic fibres. Each bronchiole in the lobule divides into several *alveolar passages* which are lined on all sides with cup-shaped cells and have distended extremities known as *infundibula*. These air cells are not unlike the acini in a racemose gland. to

which each lobule or indeed the whole lung may be aptly compared. Each bronchiole forms *the only entrance* to its lobule, so that once it is blocked all communication with the lobule ceases.

The **air-cells** are about $\frac{1}{50}$th inch in diameter, and are composed of the finest membrane lined with squamous epithelium and covered with some elastic tissue. In the lungs the cells are, of course, ever contracting and expanding, but never to their full extent.

Structure of an Air cell.

It is these elastic fibres that are seen in consumptive sputa when the air cells are destroyed.

Small openings are seen when the alveoli are distended between the cells opening into the lymph spaces below, through which the lymph corpuscles come, and carry off and store the carbon inhaled in the intercellular and interlobular tissue. The pigment seen here is not true melanin, but particles of carbon.

The **blood-vessels** of the lungs are derived from two sources, the *pulmonary artery*, which brings the impure blood to be oxygenated, and the *bronchial arteries*, which bring arterial blood to nourish the lung tissue itself.

Blood-vessels of the Lungs.

The **pulmonary artery** sends in a branch at the root of each lung, which rapidly subdivides, into a meshwork of very regular and wide capillaries, sufficiently broad to admit of the easy passage of the corpuscles.

Pulmonary Circulation.

These capillaries are so numerous that the spaces between them are narrower than the vessels, and if placed in one straight line they would reach several thousand miles. Their united area presents a surface of blood fifty-six yards square in extent, and computed to contain not less than 22,500,000,000,000 corpuscles. The united sectional area of the lung capillaries

Lung Capillaries.

is less than that of the body capillaries, so that the flow of blood in the former must be more rapid than in the latter. These capillaries unite in four pulmonary veins that bring back the arterial blood to the left heart.

The **bronchial arteries** form a separate system of capillaries around all the bronchial tubes. In the mucous membrane there are two capillary plexus, a coarser one from the pulmonary vein and a finer one from the bronchial

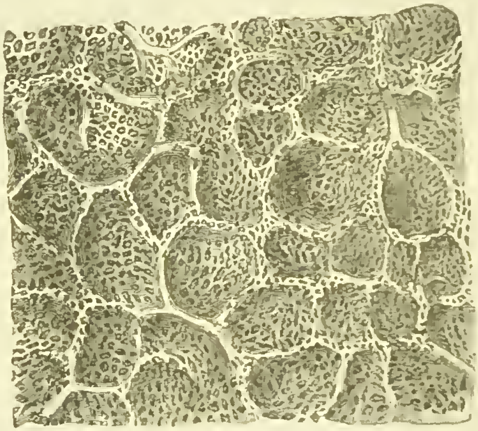


Fig. 98.—Small Arteries of the Air Cells of the Lungs.

artery; both of these plexus return by the pulmonary veins to the left heart; the blood in these bronchial capillaries being purified alike with the blood in the pulmonary by the air in the bronchus. The other and deeper bronchial capillaries return unpurified blood by bronchial veins to the vena cava and right heart.

When the lung contracts the capillaries double up like tendrils; when it is fully expanded they are quite straight. The same thing is observed in muscle when it contracts and expands.

The fact of the blood in the lining of the bronchial tubes returning by the pulmonary veins explains the catarrh or bronchitis set up by any

back pressure from heart disease, etc., thus causing congestion and exudation in the mucous membrane.

Each **pleura** consists of a closed sac, with both its sides in apposition, wrapped round the lung, excepting at its root. The outer layer, called the *parietal*, is fixed to the inside wall of the thorax, the inner, called the *visceral*, to the surface of the lungs. As the lungs move, the inner surfaces of each layer glide on each other in the manner of a large joint. In health there is no space inside the pleura.

The Pleura.

The pleura is a serous membrane, and the parietal layer consists of a dense layer of fibrous tissues overlaid with flat endothelial cells. Beneath the two is a loose mass of connective tissue with bundles of unstriped muscle, and numerous lymphatics and lymph spaces and some elastic fibres. The *visceral* layer is lined with columnar and endothelial cells that become squamous when expanded. The outer fibrous tissue of the layer is continuous with the interlobular fibrous septa and the tissue round the bronchi. This close connection of the pleuræ with the lung tissues has important bearings in disease.

Structure of the Pleura.

In health, as we have said, the two pleural layers are in close apposition; for although the lung is always on the stretch, pulling with an elastic force of $\frac{1}{4}$ to 1 lb. per square inch and tending to separate them, on the other hand, the pressure of the air exerted on the interior of the lung is 15 lbs. per square inch, thus keeping the layers together by superior force. If, however, air be admitted to the outer surface of the lung, or in other words, into the interior of the pleural sac by puncture or other communication from without, the lung at once rapidly contracts, separating the pleural layer, and collapses.

The Pleural Sac.

The **lymphatics** of the lungs are very numerous

There are at least three sets—the *subpleural* that drain the pleura; the *perivascular* that run amongst the air-cells round the capillaries, and the *peribronchial* that run in the coats of the bronchi. The lymphatics in the diaphragmatic pleura have stomata that open directly into the pleural cavity. The movements of respiration are thus active agents in the circulation of the lymph, the vessel being provided with valves.

Lymphatics of the Lungs.

The **nerves** of the lungs are derived from the sympathetic system, and the vagus or pneumogastric. The exact termination of the nerve fibres in man is not known. This double nerve supply is of the greatest importance, because it provides for both involuntary and voluntary lung movements.

The Nerves of the Lungs.

We thus can breathe without our will or mind being engaged, and on the other hand, we can alter and vary our breathing by our will within certain limits, and are thus enabled to talk, and sing, and laugh, all of which would be impossible were the lungs supplied by the sympathetic only. The *diaphragm* or thoracic floor is supplied by the phrenic nerve, and the ribs by the intercostals. The involuntary centres for inspiration and expiration lie in the medulla, and are connected with higher voluntary centres in the cortex. The involuntary centres act ordinarily automatically, but any accumulation of venous blood circulating in them stimulates them by reflex action so as to produce deeper and more rapid inspirations. So strong is this reflex action that the utmost power of the will, exerted through the higher centres, cannot overcome it, and although we can hold our breath up to a certain point, we can never commit suicide by so doing: for the reflex power of this centre overcomes all our efforts to inhibit it, and we are forced to breathe.

Voluntary Respiration.

Centres for Respiration.

The *pneumogastric* has two sets of respiratory fibres in it; the one in the superior laryngeal when stimulated slows the breathing; the other in the trunk of the nerve quickens it. It is believed that the double respiratory centres in the medulla, one for inspiration and one for expiration, discharge their force alternately.

Action of the Pneumo-gastric.

3. THE MECHANISM OF RESPIRATION.

The **mechanism** of respiration consists essentially of a dilatation of the chest by *muscular effort*, and a subsequent contraction mainly by *elastic recoil.* It must be remembered that the whole lung being forcibly stretched against the inside of the chest wall by atmospheric pressure, all expansion of the chest necessarily means expansion of the lungs. All the movements of the lungs are passive and dependent upon those of the thorax.

Movements of the Lungs.

The muscles of ordinary inspiration are the diaphragm, the intercostals, the levatores costarum, and the three scaleni.

The *diaphragm* is the most powerful respiratory muscle in the body. It is always arched towards the thorax. It forms a double dome, that on the right being the largest; this hollow being occupied by the liver, and the smaller one on the left by the spleen and stomach. The blood-vessels (vena cava and aorta) that pass through it are surrounded by tendons so as not to be compressed, and the circulation reduced in respiration. The œsophagus, on the other hand, has a muscular opening, so it is tightly closed during inspiration, thus preventing any regurgitation of food from the pressure on the stomach. The centre of the diaphragm forms a tendon on which the heart rests, and which is practically stationary during respiration. As the

Action of the Diaphragm.

muscles contract both domes get flattened, and the length of the thorax increased. As in its descent the diaphragm presses down the abdominal viscera, and these bulge out the lower thoracic walls, it follows that the thorax is widened as well.

All the other inspiratory muscles act by raising the ribs, which make the chest deeper and wider.

The action of the intercostals has been variously explained.

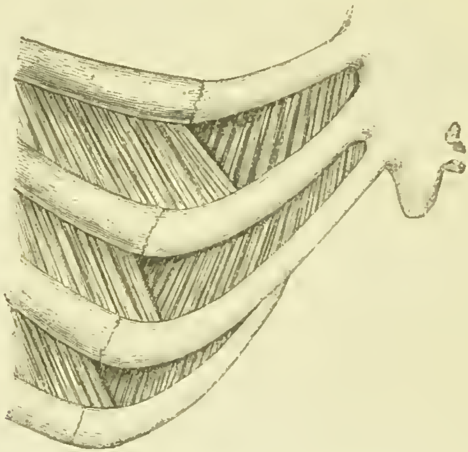


Fig. 99.—Intercostal Muscles.

Action of Intercostals.

By Galen and many others the external set are regarded as inspiratory, and the internal set as expiratory: by Haller both as inspiratory, by Vesalius both as expiratory, while Landois regards both as expiratory and inspiratory. Although opinions differ, Galen's view is the most accepted explanation of their action; that the external intercostals raise the ribs as they shorten, and are *inspiratory*; and the internal intercostals depress the ribs by contracting, and are *expiratory*. The action of the intercartilaginous muscles in front is of course the reverse of this.

Still more recent investigations, however, tend to show that both

sets are mainly for the purpose of keeping tense the intercostal spaces and preventing them bulging out in the chest movements than for respiratory purposes. Unless these spaces are kept tense great force is lost in the respiratory effort.

Movement of the Ribs.

The ribs it must be observed move on a fixed pivot at the spine. Being curved as they are raised they revolve outwards and also lift the sternum, thus increasing the chest capacity laterally and antero-posteriorly. In inspiration it must be observed that the omohyoid by its attachment to the fascia in the neck performs the valuable work of preventing the sinking in of the lung apex in inspiration.

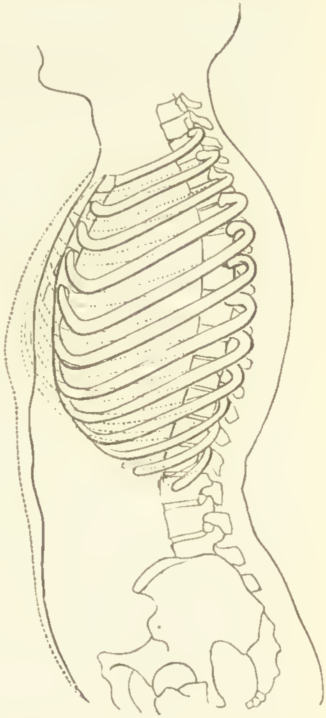


Fig. 100.—Expansion of Chest and Movement of the Ribs by Action of the Lungs.

If the effort of inspiration be great, extra muscles are brought into play—the serratus posticus superior, the sterno-mastoid, the serratus magnus, pectorales, and trapezius. All these tend to raise the ribs still more. The spinal column is also involuntarily straightened, which still further increases the chest area. At the same time the freest ingress is allowed to the air by the action of the dilator nerves and the opening of the glottis.

Force of Inspiration.

The elasticity of the ribs favours ordinary inspiration, but opposes any great effort. A great deal of the muscular force is expended in overcoming the elasticity of the lungs, and the weight of the chest walls. To inspire 200 cubic inches requires thus

a force of 450 lbs. The more the lungs are distended, the greater the proportional force required. The total force expended in respiration is estimated at 21 foot tons daily.

Types of Respiration.

The acts of respiration, and more particularly of inspiration, are of **three distinct types**. An infant when first born begins to breathe partly from accumulation of CO_2 in the blood exciting the respiratory centre, and partly from the stretching out of its body enlarging the thorax and causing a vacuum. When thus established the breathing in infants and young children of both sexes is nearly all diaphragmatic, and as this bulges out the abdomen it is known as the *abdominal* type. In men the ribs, more particularly the lower ones, take an active share in it; this type is called the *lower costal.* In girls and women the principal part of inspiration is effected by the six upper ribs, and this is called the *superior costal* type. This sexual difference was long believed to be inherent; it has now been proved to be acquired from the different clothing worn by each sex. Women who for years have dressed as men breathe like them, the difference in these two types being mainly artificial.

Expiration.

Expiration is mainly due to elastic recoil and the weight of the chest wall, but can be greatly assisted by the compression of the viscera by the abdominal muscles, and by dragging down the ribs by the triangularis sterni, the serratus posticus inferior, and the quadratus lumborum. The total force in expiration is one-third stronger than in inspiration. The muscular tissue within the lungs has little influence on respiration. It may assist expiration, but is more probably used to regulate the size of the bronchioles and prevent over-strain of the lungs. Perhaps by a vermicular motion it may help slowly to expel the mucus.

In the adult there are about $4\frac{1}{2}$ beats of the heart to

each respiration, so these are about 17 per minute. The rate of these, however, varies greatly with the activity of the body. Taking respiration when lying down as 1·0 or 17, when sitting it is increased to 1·5; standing to 1·8; in slow walking to 2·0 or 34; in cantering on horseback, easy rowing, or walking, to 3·0; in trotting, swimming, or fast walking, to 4·0; and in fast running to 7·0 or 119. The rate also decreases according to age from 40 in the infant to 17 at twenty-five, at which level it is maintained. On the whole, the smaller the animal the quicker the respiration; because in a small animal the proportion of surface to bulk is much greater than in a large animal, and hence also is the loss of heat.

Rate of Respiration.

How Increased.

How Decreased.

Thus, a worm breathes 200 per minute, a horse 10, a hippopotamus 1.

Respiration is affected by atmospheric pressure. If this be reduced one half the breathing is difficult and the interchange of gases is decreased. Increase of pressure slows the respiration, but the interchange of gases is increased.

The will can, of course, alter the number of respirations. Inspiration is slightly shorter than expiration, as 6 is to 7. In health there is no pause between inspiration and expiration, but there generally is between expiration and inspiration. In respiration there is a rustling sound heard though the chest, supposed to be due to the expansion of the air cells and the movement of the air.

Respiration, when tranquil, should always be carried on through the nasal passages and not through the mouth. The advantages of this are :—

Breathe through the Nose.

1. The air is warmed and moistened if too dry, hence all irritation is avoided.

2. It is also filtered from dust, soot, etc.

3. Any impurities (sewer gas, etc.) are more readily detected by the sense of smell.

Ordinary breathing through the mouth is only a product of civilisation. Among savages and most animals breathing through the nose is the rule.

Varieties of Respiration.

Sighing is a prolonged quiet inspiration that occurs from deficiency of air or from mental impression, often involuntarily.

Hiccough is a sudden inspiration with closure of the glottis, caused by spasmodic contraction of the diaphragm, often caused by some gastric irritation.

Sniffing is a succession of short inspirations through the nose.

Sobbing, a series of convulsive inspirations, generally through the mouth, caused by spasmodic contraction of the diaphragm.

Yawning is a prolonged and very deep inspiration, the whole respiratory tract being widely open. It is involuntary.

Sucking is an inspiration accompanied by the depression of the tongue, causing, when the mouth is immersed in any liquid or closed around a nipple, an inrush of fluid from the pressure of the air.

Snoring occurs in respiration through the mouth only, whereby the soft palate being set in vibration by inspiration and expiration, the characteristic sound is produced.

Laughing is a series of short, sharp expirations, either with or without sound, according as the vocal cords are closed or open.

Speaking and *singing* are expirations with the vocal cords nearly closed by which the sound is produced, the articulation being formed in the mouth.

Coughing is an explosive expiration following a deep inspiration, by which the closed vocal cords are forced open, and any substance irritating the bronchial mucous membrane is forcibly expelled. The chief causes of cough are

irritation of the pharynx, of any part of the bronchial tubes, of the stomach (stomach cough), or from cold air striking the chest walls.

Sneezing is the same as a cough, only it is through the nose.

Crying is a series of short, deep inspirations, with long expirations, and frequently excessive secretion of tears.

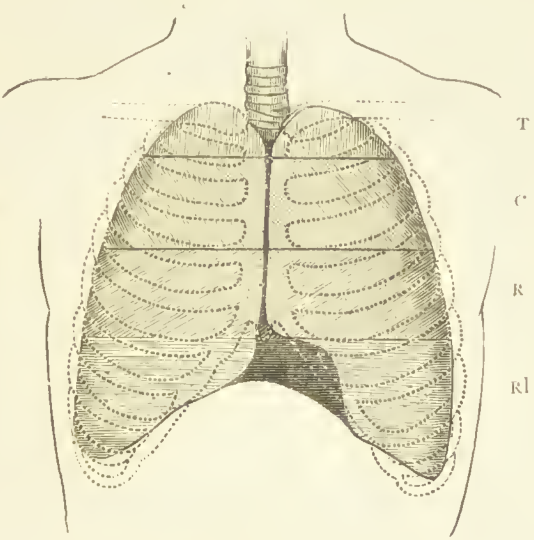


Fig. 101.—Diagram of Capacity of Chest.
T Tidal air. C Complemental. R Reserve. Rl Residual.

The extent and capacity of the lungs obviously varies with the age and size. In a full-grown man, five feet eight inches high, the amount of air ordinarily breathed in tranquil respirations is 30 cubic inches; this is called *tidal* air. A forced inspiration can take in 100 cubic inches more of *complemental* air. In the same way a forced expiration can get rid of an extra hundred inches of *reserve* air; after which, however, there still remains in the chest 100 inches of fixed or *residual* air that no expiration can get rid of.

Lung Capacity.

It will thus be seen that the *vital capacity*, or the utmost air that can be expelled from the chest after the most forcible inspiration, is 230 inches; over 11½ stone weight a man loses 1 cubic inch for every pound. From 15 to 35 the vital capacity increases at the rate of 1½ inches per annum; from 35 to 65 it decreases about 1½ inches per annum. The vital capacity of woman in this, *as in most other physical ratios*, is in the proportion of 7 to 10. The amount of air ordinarily breathed amounts to 686,000 cubic inches in 24 hours.

Vital Capacity.

Having now considered at length the mechanism of respiration, we turn to the work done by it in the interchange of gases.

4. FUNCTIONS OF RESPIRATION.

Inspired air consists, if fairly pure, of **21** per cent. oxygen and 79 per cent. nitrogen, by volume; or 25 per cent. oxygen and 75 per cent. nitrogen, by weight. In addition there is about 1 per cent. of watery vapour, and **·05** per cent. of CO_2. There is also a variable quantity of dust, microspores, and other impurities. The air is generally cold or cool.

Composition of Inspired Air.

Expired air differs from inspired air in that it is warmer (generally 98·6), there is an increase of CO_2 and a diminution of O; the composition being now **16** per cent. oxygen, 79 per cent. nitrogen, and **5** per cent. CO_2. The air is moister, being generally saturated with watery vapour. It is free from all inspired dust and impurities. It contains decomposing organic matter to the amount of about 3 grains per 24 hours. There is also a little free ammonia, which probably comes from the mouth and teeth. It is about $\frac{1}{50}$ less in volume, that is, if reduced to the same temperature. Being of a much higher temperature, the actual volume of expired air

Composition of Expired Air.

is about $\frac{1}{9}$ greater. This decrease of volume represents an extra amount of O absorbed, possibly used in the CO_2 given off by the skin.

A very little nitrogen may be absorbed when fasting. This relative amount of CO_2 given off and oxygen retained varies from many causes. The amount of CO_2 in grains excreted per hour averages 632, or 8 ounces of solid carbon per diem.

Relation of Oxygen to CO_2.

By volume, 18 cubic feet of CO_2 are expired, and rather more than this of O are inspired every hour.

Men give off more CO_2 than women, in the ratio 10 to 7.

The more muscular and energetic the person, the more is the amount of gases interchanged. Exercise can increase CO_2 to one-third more. The CO_2 expired increases in men from 8 to 30, and from 30 to death slowly diminishes. In women it increases from 8 to 15, then remains the same to 45, and then decreases.

CO_2 is increased by—	CO_2 is decreased by—
sex (men),	sex (women),
exercise and work,	sleep and rest,
age (youth),	age (old age),
temperature (cold),	temperature (heat),
food (carbohydrates),	*alcohol*,
increased number of respirations,	impure air,
pure air,	dryness,
moisture,	season (autumn),
season (spring),	beginning of expiration.
close of expiration.	

More CO_2 is produced in the day than O absorbed. The amount of O absorbed at night is *nearly double* that of the day.

Day and Night Respiration.

Of 100 parts of CO_2 expired per hour, 52 will be given off by day and 48 by night; of 100 parts of O inspired per hour, 33 parts will be inhaled by day and 67 by night. On the other hand, one observer (Lewin) states that O is not stored up during sleep.

The warmer the external temperature the less CO_2 evolved, the warmer the internal temperature the more. Food, especially carbohydrates, increases the amount of CO_2, alcohol diminishes it.

Causes Affecting CO_2.

The quicker the respiration the less CO_2 is expired each time, though the total amount per hour is slightly increased.

The more CO_2 in the air the less is given off by the lungs.

The moister the air the more CO_2 is expired.

Most is given off in spring, least in autumn.

The last half of an expiration contains more CO_2 than the first half.

The amount of water given off by the lungs is about half a pint in the 24 hours.

It is obvious that with a tidal respiration of only 30 cubic inches, it is only the air in the windpipe and larger bronchi that is ever actually exchanged: nevertheless the O inspired reaches the remotest air cells, according to the law of diffusion of gases, whereby they diffuse in inverse proportion to the square root of their densities. By the tidal movement being so slight the delicate air cells are spared the great friction that would result if all the air were changed, while the above law ensures that the CO_2 in the deepest tissues and the O above speedily change places.

Interchange of Gases.

The actual **exchange**, however, between the gases of the blood and those of the air cells is almost entirely a chemical process, and largely independent of the above law, as these gases are not free in the blood. The whole process is as yet imperfectly understood.

Change of Gases in Blood.

The relative tensions at first sight favour the idea that the process is one of simple diffusion, for the tension of O in venous blood=41mm. of mercury, in the air 158: that of CO_2 in venous blood=41mm., in the air 0·38.

That it is a chemical process, however, and not due to diffusion is proved, because even in an atmosphere of O the blood only takes up the same fixed amount, whereas if due to diffusion there would be a great excess. Oxygen probably diffuses from the alveoli into the blood plasma, and is then taken up in chemical combination by the reduced hæmoglobin, which then becomes oxy-hæmoglobin. Oxygen in the blood is never free, but always in combination with hæmoglobin. Hence we find it is easier to make venous into arterial blood by O than it is to make arterial into venous by CO_2, because the arterial corpuscles will not give up their O without some oxidising agent present.

Entrance of Oxygen into the Blood.

The passage of CO_2 out of the blood is favoured :—(1) by the law of diffusion; (2) by the affinity of CO_2 for a moist membrane, across which it easily passes; (3) the presence of hæmoglobin, which is supposed to play the part of an acid.

Passage of CO_2 out of the Blood.

In the blood the CO_2 exists in the serum in a state of loose chemical combination.

The whole process is explained by Donders as being due to pressure, certain chemical compounds formed under pressure becoming separated when the pressure is removed. The CO_2 in the plasma and the oxygen in the hæmoglobin are said to be of this nature. The CO_2 combines with the plasma in the body cells where the amount of it is great and separates in the lungs where it is small. The O combines in the lungs where the pressure of O on the air cells is great (158 mm.) and separates in the tissues where it is small. Some again think the alveolar cells play an active part in the interchange.

In the pulmonary circulation the blood not only changes colour but becomes cooler and coagulates firmer.

In **internal respiration** the process of the lungs is reversed. In the body tissues oxygen is given up by the capillaries and oxidised by the tissues, while by a separate process CO_2 is absorbed from the waste products by the blood and lymphatics.

Internal Respiration.

The internal respiration is thus still less of a direct exchange of gases than the process in the lungs. That arterial blood becomes venous in the limbs has been proved by experiment after death. If a limb be cut off and arterial blood be forced into the arteries venous blood issues from the veins.

The muscles are the largest producers of CO_2. The blood itself being a living tissue uses up O and produces CO_2, so do the tissues of the lungs.

If the supply of air for breathing be insufficient the breathing becomes first rapid (*hyperpnœa*), then difficult (*dyspnœa*), and then ceases (*asphyxia*). Dyspnœa occurs from want of O even when there is no excess of CO_2, but not from excess of CO_2 if there is abundance of O.

Dyspnœa.

Asphyxia itself consists of three stages:—(1) Exaggerated breathing, passing into (2) Convulsive spasms, and ending in (3) Exhaustion, general paralysis of inspiration, and death. In death from asphyxia the heart is full of blood and the blood is venous all over the body. Asphyxia takes place whenever 10 per cent. of CO_2 takes the place of 10 per cent. of O. It occurs more rapidly from want of O than by poisoning by CO_2.

Asphyxia.

In a small confined space death occurs from want of O and is very painful; in a larger space partly from this and partly from CO_2, which narcotises and causes a less painful death.

In pure O breathing becomes suspended (*apnœa*) owing to the saturation of the blood and the want of CO_2 to stimulate the respiratory centres. Such is the condition of intrauterine life, and can be produced temporarily for a very short time by numerous deep, rapid inspirations.

Apnœa.

Normal respiration is known as *eupnœa*.

If the amount of CO_2 in the air be under ·06 per cent. it is not injurious; if it is ·08 it becomes offensive, and if 1·0 it is very foul. To keep air indoors under ·06 requires 1,000 cubic feet of space for each person, and an allowance of 3,000 feet of air per hour.

Pure Air.

Health greatly depends on ventilation. In the Foot Guards, where each man had 330 cubic feet, the consumptive death rate was 13 per cent.; in the Horse Guards, where they had 570 feet, it was only 7; and in the army generally improved ventilation has reduced the consumptive death rate from 8 per 1,000 to 3.

No gas without sufficient O can support life. Harmless gases, such as nitrogen and hydrogen, thus cause suffocation in 2 to 3 minutes.

Gases poison either by displacing O, such as CO; or by simply taking it away, such as H_2S; or by narcotising, such as CO_2; or by intense irritation, such as Cl. Impurities in the air are absorbed by the lymphatics and leucocytes. Part is returned by the action of the ciliated epithelium. They may be injurious (*a*) by irritation, such as steel filings, or by (*b*) infection, as micro-organisms; or they may be harmless, such as coal dust; or they may be positively to some extent nutritious, as in wood dust, which is said in many cases to be assimilated, and in wood-turners to increase the body weight.

Poisonous Gases.

Ordinary sputum contains epithelial cells, leucocytes, and mucus. In disease it may contain blood, elastic tissue, bacilli, etc.

CHAPTER XIII.

THE KIDNEYS.

I. STRUCTURE OF THE KIDNEYS.

WE have seen that the body possesses three excretory organs which excrete three waste products; that CO_2 and water are given off by the lungs, water mainly by the skin, and water and urea by the kidneys. The fæces largely consist of the indigestible refuse of food, and, though mixed with waste products, are not therefore true excretions.

Three Excretions.

The **kidneys** are two in number, each one being

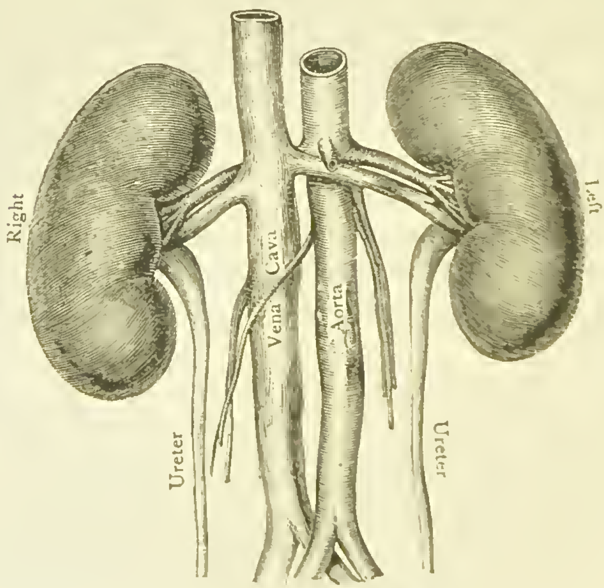


Fig. 102.—The Kidneys.

4 inches × $2\frac{1}{2}$ × $1\frac{1}{2}$, and weighing $4\frac{1}{2}$ oz. They are situated just by the sides of the last two dorsal and the first two lumber vertebræ, the right one being a little lower than the left on account of the liver. In shape the kidney is like a bean, while from the hilus, or most concave part, a tube (the *ureter*) comes off, some 12 to 16 inches long and as thick as a goose-quill, and passes downward to a pyriform sac situated just behind and above the pubes, called the *bladder;* a short tube called the *urethra* enables the contained fluid to be excreted.

The Kidneys.

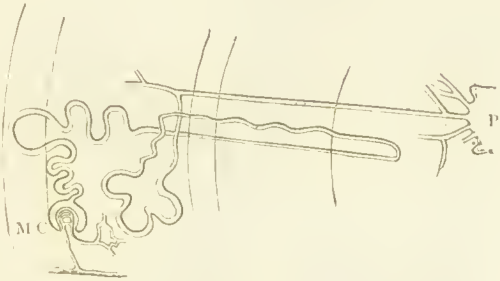


Fig. 103.—Course of Urinary Tubule from Malpighian Corpuscle to the Pelvis.
M C Malpighian Corpuscle. P Pelvis.

A kidney is a firm, fleshy body, covered with a thick, fibrous membrane called a *capsule*, which in health is easily detached, but is more or less adherent in disease. If a kidney be grasped with its concave side resting on the hand and split longitudinally along the convex surface, its structure will be well seen.

Their Structure.

We observe at once that it is hollow in the centre (called the *pelvis*) where the ureter begins, and that the solid part is easily divisible into two—an outer and deep red layer, called the *cortical* part, and the deeper and paler layer, called the *medullary* part.

Section of Kidney.

This latter mainly consists of some twelve *pyramids* (*of Malpighi*), their apices directed towards the pelvis; the apex of each being received (like a finger in a glove) into a little diverticle or cap of the pelvis called a *calyx*, into which the pelvis divides. This medullary

The Pyramids.

Fig. 104.—Malpighian Corpuscles from the Cortical Portion of the Human Kidney. (Frey.)

portion may be subdivided into the outer or basal part of the pyramids, called the *boundary layer*, and the apices, called the *papillary* layer. The cortex occupies about one-third of the thickness, the boundary layer a little less, and the papillary a little less.

The cortex is friable and granular owing to the *Malpighian corpuscles*, the medulla much denser and more striated. At regular intervals bundle of tubes (of which the medulla is mainly composed) ascend from it into the cortex, showing the original subdivision of the gland into lobules. These, getting narrower as they ascend, are called the *pyramids of Ferrein* or *medullary rays*, their apices pointing outward instead of inward as the pyramids of Malpighi, already described. The kidney is a compound tubular gland, being mainly composed of masses of tubules, which commencing in dilated extremities, called Malpighian corpuscles, in the cortex pursue a very devious course, until they at length discharge their contents into the pelvis by twenty to sixty orifices at the summit of each papilla or pyramid.

Tubules and Corpuscles.

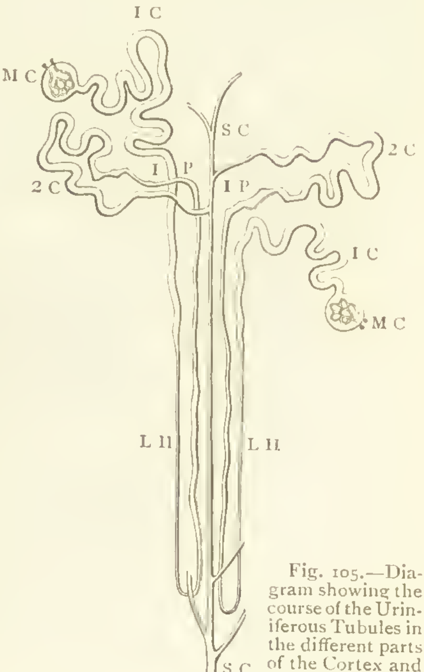


Fig. 105.—Diagram showing the course of the Uriniferous Tubules in the different parts of the Cortex and Medulla.

M C Malpighian Corpuscle. I C First Convolutions. L H Loop of Henlé. I P Irregular Portion. 2 C Second Convolutions. S C Straight Collecting Tube.

Each **tubule** commences in the cortex by a *glomerulus*, or tuft of capillary blood-vessels, enclosed in the dilated extremity of the tubule, the whole forming a **Malpighian corpuscle**, of which there are in all some 500,000 ($\frac{1}{125}$ in. diameter).

Course of the Tubules.

A narrow stratum of the cortex beneath the capsule above (subcapsular), and another next the medulla below, contain no corpuscles.

The whole length of the tubule is about two inches (52mm.); its size $\frac{1}{600}$ in. diameter. It consists throughout of a membrane lined with epithelium. It leaves the corpuscle by a neck so constricted that no lumen can be seen in the tubule at all. The tube is then twisted much on itself, forming the *first* or *proximal convoluted* portion;

Fig. 106.—From a Section through the Cortical Substance of the Kidney of a Human Fœtus, showing a Malpighian corpuscle.

a, Glomerulus; *b*, tissue of the glomerulus: *c*, epithelium covering the glomerulus; *d*, flattened epithelium lining Bowman's capsule; *e*, the capsule itself: *f*, uriniferous tubules in cross section.

it then becomes vertically spiral, forming part of a *medullary ray* in the cortex, and then, passing into the medulla, descends right through the boundary layer in a very fine tube, bends on itself and comes up again to the cortex forming a *loop of Henlé*. As the tube enters the boundary layer on its ascent it suddenly enlarges to its first calibre until it reaches the cortex, when it narrows again. It then becomes irregular in size and makes a few very sharp angular turns (the *irregular portion*). which, becoming more

rounded, leads into another twisted part (the *second* or *distal convoluted portion*). It then forms a *straight collecting* tubule, which for the first time joins with others as they

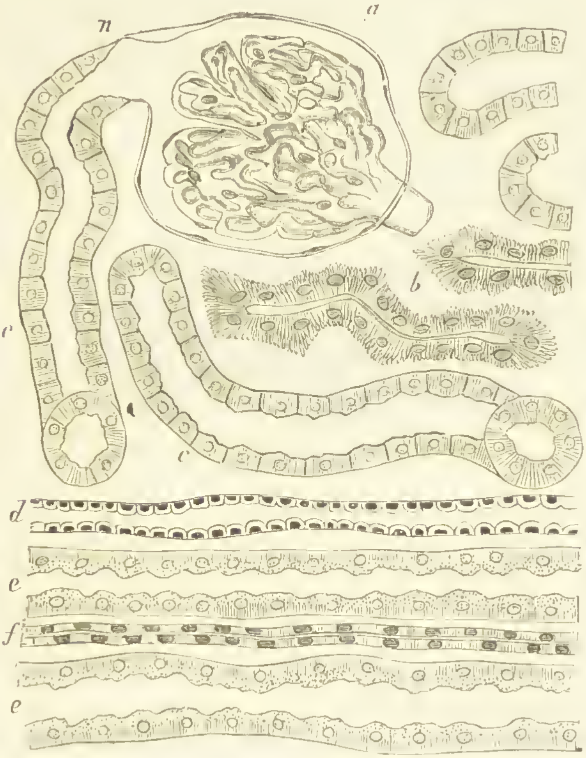


Fig. 107.—From a Vertical Section through the Kidney of Dog, showing part of the Labyrinth and the adjoining Medullary Ray.

a, The capsule of Bowman; the capillaries of the glomerulus are arranged in lobules; *n*, neck of capsule; *b*, irregular tubule; *c*, proximal convoluted tubules; *d*, a collecting tube; *e*, part of the spiral tubule; *f*, portion of the ascending limb of Henle's loop-tube; *d*, *e*, *f* form the medullary ray.

descend to form first *collecting* tubes and finally *discharging* tubes at the summit of the papilla.

This tubule is lined throughout by a single layer of epithelial cells, but possessing different characters. The

Malpighian corpuscle itself is composed of a single layer of flattened epithelium resting on a hyaline membrane. The first convoluted and the spiral portions are lined with *cloudy* cells; the part of the cell next the membrane being striped by short rods at right angles to the basement membrane, while the inner half of each cell is granular and contains the nucleus. In the descending part of Henlé's loop, which resembles a blood-capillary save for its basement membrane, the cells are clear and flat, with a nucleus that bulges

Structure of Tubule.

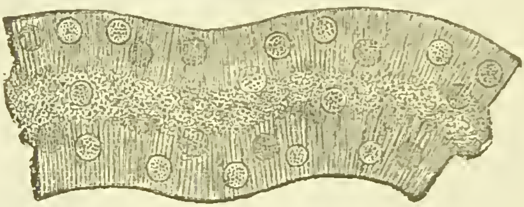


Fig. 108.—Portion of Convoluted Tubule showing peculiar fibrillated Epithelial Cells. (Heidenhain.)

into the lumen, which is so narrow that the two nuclei cannot lie opposite to each other. In the wider part of the ascending limb the cells become striped and cloudy as in the first convoluted portion. The irregular and second convoluted portion have cells like the first, while the collecting tubules have clear cubical epithelium which becomes columnar in the discharging tubes. The basement membrane all through is well marked save in the collecting and discharging tubes.

Summary.

From the above description it will be seen that the *cortex* contains the corpuscles and the first and second convoluted and the spiral and irregular portions of the tubules; the *boundary* layer is made up of Henlé's loops and the collecting tubules, while the *papillary* layer mainly consists of the larger collecting and discharging tubes.

The **blood supply** of the kidney is of great importance. It arrives by a short artery, the *renal*, direct from the aorta, which passes in at the hilus of the kidney by four or five branches, which subdivide and passing round the pelvis enters between the papillæ by the columns of Bertini, which are downgrowths of the cortex near the junction of the boundary and cortical layers.

Blood Supply.

Here the arteries form *incomplete horizontal arches*, from the *upper* surface of which the interlobular arteries run straight up towards the surface of the cortex between the medullary rays. Each artery gives off at regular intervals on each side the short afferent artery to the **glomerulus** of the Malpighian corpuscle, which hangs at its end like a raspberry on its stalk.

Outer Arterial System.

The artery suddenly breaking up into the circular tuft of capillaries, united by fine connective tissue, seems at first to have pushed before it the dilated extremity of the tubule, so that a double layer is wrapped round it just as the pleura round the lungs, the terminal end being just separated enough to allow the afferent and efferent vessels to pass. From the very centre of this glomerulus the small efferent vein emerges, leaves the capsule, and at once breaks up into a second set of capillaries that closely surround the first convoluted portions and the tubes (irregular and distal convoluted) in the medullary rays. These unite into veins, which descend to the boundary layer, there to form *complete arches*, and finally to leave the kidney where the artery enters it.

Glomerulus.

From the *under* surface of the incomplete arterial arches straight arteries spring that run downward between and parallel with the tubules in the medulla, giving off a network of capillaries and finally forming veins which ascend and enter the

Inner Arterial System.

concave side of the complete venous arches. The capillaries of these two systems, outer and inner, are connected, but the value of this alternative inner channel for the blood, without traversing the glomeruli, is obvious in cases of congestion of the kidney.

Function of the Corpuscle.

The two layers in the capsule of the Malpighian corpuscle are often found fused together, and can seldom be made out; and as the water of the blood is strained off here, the corpuscle has been compared to a filter, of which the capsule forms the filtering paper.

Blood Loses Urea at Kidney.

Considering that the organic impurities of the blood are mainly excreted by the kidney, and that the blood arrives there just after traversing the lungs and left heart, it is obvious that the blood is only purified in the lungs of its CO_2, and not of urea.

Red Venous Blood.

The blood that issues from the renal veins is as bright red as that in the renal artery, and is actually **the purest blood in the body**; any little CO_2 formed by the action of the kidney being excreted in the urine. This renal blood flows into the inferior vena cava.

The blood supply of the kidney is particularly large and rapid, because it arrives at high pressure from the aorta, and returns at very low pressure into the vena cava.

Lymphatics and Nerves.

The *lymphatics* are numerous, and surround the blood-vessels, save in the glomeruli, where no lymph spaces have been discovered. The *nerves* are derived from the renal plexus and the lesser splanchnic nerve. They have not yet been traced to the epithelium of the tubules. The intertubular fibrous tissue is scanty, and a few smooth muscle fibres are interspersed with it. Beneath the capsule and round the apex of the pyramid they are more numerous.

2. THE URINE.

The fluid secreted by the kidneys is called **urine**. It is transparent, amber, bitter, acid, and has a peculiar odour. Its sp. gr. is about 1020, and the daily amount in health averages 52 ounces in the adult.

Urine.

Its composition is :—

Water	95·7
Urea	2·4
Other organic bodies	1·0
Salts	·9
	100·0

Chemical Composition.

There is probably a trace of sugar, and some CO_2 is always present. In disease urine may contain, in addition, blood, albumen, sugar, bile, casts, etc.

The daily amount passed (by weight) of these substance is as follows :—

Water	52 ozs.
Urea	512 grains.
Uric Acid	8 ,,
Hippuric Acid	15 ,,
As Salts—	
Sulphuric Acid...	31 ,,
Phosphoric Acid	45 ,,
Potassium, Sodium, Ammonium, and Chloride	323 ,,
Lime	3 ,,
Magnesia	3 ,,
Mucus	7 ,,
Extractives—	
Creatinin, etc.	154 ,,

Its *colour* varies much, according to the amount of pigment present, from the clearness of water, as at times in hysteria, to the dark-yellow or brownish-red seen in the early morning. In disease it may be black, brown, orange, or (rarely) bluish. As it decomposes it shows fluorescence.

Its Characteristics.

The *taste* and *smell* largely depend on the food taken; turpentine gives the odour of violets; assafetida, of onions; while in diabetes it has a "sweet" smell.

The *acidity* is not due to free acid, but to the presence of an acid salt—acid phosphate of soda, which is derived from the ordinary phosphate of soda by the uric and hippuric acids taking away part of the soda. That it contains no free acid is proved by no precipitate being found with sodic hypophosphite. The urine becomes *more acid* by standing a short time, from acid fermentation, or when acids are taken, or after prolonged exertion, and by an excessive animal diet. It becomes *less acid*, or alkaline, by alkalies, by the pressure of blood during digestion, by much vegetable food, by profuse sweating and by standing a long time, from the decomposition of urea and the forming of $AmCO_3$ by the *microsporon ureæ*.

Acidity.

The *specific gravity* varies from 1015 to 1025, in health. Copious draughts of water may, however, reduce it temporarily to 1002, while, on the other hand, the absence of fluids, and profuse perspiration, may raise it to 1040. In infants it is about 1004. In disease it is decreased by the presence of albumen, and increased by sugar. The solids in 1,000 parts, in grammes, can be obtained by multiplying the last two figures by 2·3, or more roughly by simply doubling them.

Specific Gravity.

Thus urine of 1025 sp. gr. contains 57·5 grammes of solids in 1,000 parts, or more roughly 50 grammes.

The specific gravity is ascertained by the urinometer. which floats freely in the urine; the specific gravity of the sample being read off where the fluid touches the tube.

The *quantity* of urine varies greatly. It is about 48 ounces in the female and about 52 in the male. Least is secreted between 2 and 4 a.m., and most between 2 and 4 p.m.

Quantity of Urine.

It is *decreased* by sweating, dry food, lessened blood

pressure, and hæmorrhage. It is *increased* by much fluid, by increased blood pressure, by cold, and a dry skin, by drugs, and in disease by sugar. It is also influenced by the nervous system. It is often profuse in hysteria.

Urea is the principal organic constituent of urine, and the kidneys may be said to be specially employed in its excretion. Urea forms half of all the solids in the urine. It is itself a diuretic drug, and if injected into the body it produces a filtration of watery urine through the tubules even when all action of the glomeruli are stopped by section of the spinal cord. Its formula is CH_4N_2O, and it is isomeric with ammonium cyanate NH_4CNO. Its composition is simple —one part of CO_2, and two of ammonia less one of water— $CO_2 + 2\,(NH_3) - H_2O = CH_4N_2O$.

Urea.

It is the chief remover of the nitrogenous waste of the body. On heating or standing it separates into $AmCO_3$ and cyanic acid by taking up two molecules of water, $CO(N2H_2)_2 + CH_2O = CO(NH\ O)_2$.

With nitrous acid it splits up into H_2O, CO_2, and N, and by this means its quantity is easily estimated. Its *presence* is found by adding nitric acid to the concentrated urine, when flat crystals of nitrate of urea will be formed after a while. The *quantity* is found by decomposing a known amount of diluted urine with sodic hypobromate, and the N given off rises to the upper part of the tube, which is graduated so as to give the percentage of urea shown by the amount of' N $N_2H_4CO + 3NaBrO = 3NaBr + CO_2 + 2H_2O + N$.

Tests.

It can also be calculated on the basis that a known weight of mercuric nitrate will precipitate a certain amount of urea. This salt is added to the urine till all the urea is thrown down, and the calculation made.

Urea itself is colourless, has no smell, neutral reaction, and a cool nitre-like taste.

The average quantity is 2·5 to 3·0 per cent. of the urine, or 500 grains daily. In children there is twice as much in proportion to their weight. As a rule the amount of N taken in the food is balanced by the amount excreted in urea. Nitrogen forms half of urea by weight. The quantity is increased by animal diet, and by rapid nitrogenous waste, as in fever. It does not vary according to the amount of urine, but is generally more with increased urine, even when this is produced by drinking water. A vegetable diet decreases it, and muscular exercise as a rule does not increase it.

Quantity.

This important fact was proved by Haughton, who found that in a daily walk of twenty miles less urea was secreted than in a daily walk of five miles.

Urea forms $\frac{1}{10000}$ of the blood, and $\frac{1}{2000}$ of the lymph. It is uncertain where it is formed, but some is produced in the liver and lymph glands. Kreatin is probably a source of it.

Urea found in the Blood.

Uric acid is the substance which next to urea carries off the nitrogen waste of the body. It is colourless, tasteless, odourless, and crystallises in sharp needles. The urea of birds and snakes contains great quantities of it.

Uric Acid.

An animal diet increases and a vegetable diet decreases it. In gout it is deposited in the joints as urate of soda.

About 8 grains is formed in the 24 hours. The proportion of urea to uric acid is as 45 to 1. It is generally deposited in the urine as a brick-red powder of acid urate of soda and potash. Free uric acid is not common in urine.

The presence of uric acid is shown by the murexide test. A few drops of HNO_3 are added to the urates and heated. When evaporated and cooled, if a drop of AmHO be added, a beautiful purple colour appears, which turns blue with KHO.

Tests for Uric Acid.

Another test is to dissolve the urates in a solution of $NaCO_3$ and drop a little on a filter paper soaked in $HgNO_3$, when a black spot appears.

Hippuric Acid.

Hippuric acid averages about 15 grains a day. It is the chief excretion of herbivorous animals, being greatly *increased* by a vegetable diet. It is believed to be formed in the kidneys by the combination of benzoic acid in the blood with glycin produced by the renal epithelium.

Kreatinin is another nitrogen excretion and is a hydrate of kreatin formed in muscle.

Oxalate of lime occurs occasionally, especially after eating rhubarb.

The *colouring* matters of the urine are *urobilin* and *urochrome.*

Urobilin is an orange pigment probably derived from bile, and most abundant in fevers.

Urochrome is a yellow pigment, and is regarded as the chief colouring matter of urine. Its source is unknown.

Indican, phenol, lactic acid, and traces of *ferments,* also occur in small quantities.

The *inorganic salts* are chiefly chloride of sodium (daily 180 grains) and phosphates (30 grains daily). The sodic chloride is greatly decreased in disease.

Sulphuric acid is found combined with various alkalies.

Triple phosphates of calcium, ammonium, and magnesium, are found in diseased and decomposing urine.

Decomposition.

When urine stands a short time it first becomes more acid through the formation of acetates from the presence of a small fungus, but after a time it gets alkaline from the presence of the *micrococcus ureæ,* which, causing the urea to take up water, decomposes it into ammonium carbonate and cyanic acid.

Diseased Urine.

Albumen is the most important pathological addition to the urine, but may occur apart from actual disease, after severe nervous strain or excess of nitrogenous food.

Its presence is detected by floating a little urine on cold nitric acid. If present a white disc of albumen will be found when the fluids join.

Blood (with or without corpuscles), bile, sugar, cystin, leucin, tyrosin, and various deposits, casts or fragments of renal epithelium, gravel, and stones, are all found in the urine in various diseases.

3. SECRETION OF URINE.

Filtration and Excretion.

The **Secretion of Urine** is a twofold process in the kidneys:—(1) *Filtration of water and salts*, which mainly occurs in the Malpighian corpuscles; and (2) *Excretion of the solids*, which occurs in the convoluted tubules. The process in the corpuscles is not however a process of simple filtration, for none of the serum albumen of the blood is allowed to pass through. It seems probable that the capsular epithelium has a selective influence. Nevertheless, that the process here is mainly one of filtration, and not of secretion, is seen in the difference between the action here and in the salivary and other glands.

Hence the amount always *varies directly* with the blood pressure in the glomerulus, or, more accurately, with the difference between this and the pressure in the blood tubules. The amount of urine (which is all filtered off here) is affected by the quantity of blood, the activity of the circulation, the influence of the nerves, and the action of the skin.

The amount is **increased** by—

Causes of filtration.

1. Increased *general* blood pressure—(*a*) increased amount of fluid in blood from drinking, etc.; (*b*) increased action of the heart: (*c*) constriction of blood-vessels elsewhere, as in the skin.

2. Increased *local* blood pressure relaxing the renal but not other arteries by (*a*) division of the renal nerves; (*b*) division of the splanchnic nerve; (*c*) puncture of floor of fourth ventricle.

If the floor be punctured close to the origin of the pneumogastric nerve you get diabetes mellitus (copious urine and sugar) from injury to the vaso-motor centres of kidney and liver; if it be punctured just above you get diabetes insipidus (copious urine without sugar) from injury to kidney centre only.

On the other hand, the amount is **diminished** by—

1. Diminished *general* blood pressure—(*a*) by lessened activity of heart; (*b*) by dilatation of capillaries; (*c*) by section of spinal cord.

2. Diminished *local* blood supply—(*a*) by constricting the renal artery indirectly, by irritating renal or splanchnic nerve; (*b*) by irritation of the spinal cord.

Pressure in the Glomerulus.

The blood pressure within the glomerulus is increased by the efferent vessel being much smaller than the afferent, and by the immediate occurrence of a second set of capillaries. At the same time, owing to the efferent vessel leaving from the middle of the glomerulus, a *safety valve* is provided in cases of over-pressure; for it is evident with this arrangement the greater the distension in the capsule the *less* the pressure in the efferent vein.

Safety Valve action.

Excretion.

The epithelium, striated and granular, of the convoluted tubes seems to be the *special excreting part* of the kidney. It is believed these cells take the waste products, principally nitrogenous, out of the blood, and that the water and salts filtered off above in the corpuscles wash them down the tube.

The following experiment seems to show this:—Sulpho-molybdate of soda injected into the blood is found in the cells of the convoluted tubule, and if the Malpighian corpuscles be destroyed it remains there, but if they act

it appears in the tubule itself and is washed down with the urine.

The experiment of Nussbaum to show the same thing—being dependent on the facts that in the frog the corpuscles are supplied by the renal artery, the convoluted tubules by the renal-portal vein—has been found to be unreliable, as a communication exists between the two blood supplies.

The epithelium in the convoluted tubules is therefore believed to be truly secreting like that in the salivary glands. As we have said, the lining of the capsule is partly of the same character, having the power of excluding albumen, which if it is unhealthy it lets through.

Respecting the formation of urea, it is probable that it is formed in the blood and excreted by the kidney; for the kidney does not secrete like the liver or salivary glands. If these be stopped no bile or saliva is formed, because their source is stopped; but if the kidney supply be stopped urea appears in the blood, showing that the kidney is not an organ to manufacture a fluid for use in the body, but to excrete useless matter only, which but for it would accumulate.

Urea, where formed.

Urea exists in the blood. It is not found in the muscles or nerves, but in very small quantities in the liver. In acute liver disease the urea rapidly diminishes.

Urea is probably partly obtained from nitrogenous food, because it increases with abundant meat diet; and partly from the tissues, because it occurs when no N is taken.

A theory, not yet proved, as to the origin of urea is, that it is formed from the kreatin of muscle. This can easily be split up into urea and sarcosin; and the sarcosin, which is methyl-glycin, also converted into urea. (If glycin is given the urea is increased.)

Kreatinin, of which a very small amount is excreted, evidently does not account for all the kreatin made; and, seeing the excretion of kreatinin is stopped by starvation and increased by flesh diet and not by muscular exercise or waste (fevers), it is probable it is the product of the kreatin in food rather than in the body muscles.

Uric acid has probably the same two sources, and is not formed by the kidney, but is taken out of the blood. It also increases when not excreted.

Uric Acid, where formed.

Hippuric acid is probably actively formed by the kidneys by combination of benzoic acid in the blood with the glycin they make. It is probably derived from vegetable food.

The size of the kidney varies with the amount of blood in it. These variations can be recorded by the *oncograph* and *oncometer*, by which the kidney is enclosed in a metal chamber filled with oil, communicating by a pipe with a second chamber in which is a float and a writing lever, so that the fluctuations in the size of the kidney, displacing the oil, move the fioat up and down, and so produce a tracing on paper.

The connection between the skin and kidneys is well known. If the skin of a dog is washed with acid water the kidney contracts rapidly at the same time; and the secretion of urea and sweat is in inverse proportion.

Skin and Kidneys.

4. URETER AND BLADDER.

The **ureter** is a tube the size of a goose-quill, and twelve to sixteen inches long, that leaves the pelvis of the kidney to enter the bladder. It is composed of four coats—fibrous, muscular, submucous, and mucous. The muscular coat is of smooth fibre arranged in three layers, the central being circular, and the other two longitudinal. The submucous coat is composed of adenoid tissue with a few mucous glands. The epithelium of the mucous membrane is in several layers, the most superficial being spheroid, the next pear-shaped with long processes, and the deepest oval.

The Ureter.

The ureter enters the bladder obliquely, lying for three-quarters of an inch between its muscular and mucous coats, which compress it and form a valve at its entrance.

Passage of the Urine.

The urine moves along the ureter by—

1. The vis a tergo of continual fresh secretion.
2. Gravity when erect.
3. The peristaltic contraction of the muscles of the ureter.

The Bladder.

The **bladder** is a pyriform abdominal bag in a child, ovoid and pelvic in the adult, and consists of four coats arranged like those of the ureter, only the outer one instead of being fibrous is *serous*, being composed of peritoneum, and only covers the upper and back parts of the bladder.

In the submucous coats there are also elastic fibres which maintain the bladder when empty in a state of rugose contraction. The nerves are derived from the sacral (spinal) and hypogastric (sympathetic) plexuses. These centres are purely reflex and would act unconsciously were not the spinal centre controlled by a higher one in the brain. This can inhibit or excite the lower centres, and can also bring extra muscles into play to aid micturition when needed, the action therefore being partly voluntary and partly involuntary. The exit of the fluid is prevented by the *sphincter urethræ*, a circular band of striped muscle fibre around the lower half of the urethra by which the urine is discharged at intervals controlled by the will.

Micturition.

A healthy bladder when full contains a pint of fluid. and is emptied at intervals by micturition. The urine passes into the bladder slowly by drops. The desire for micturition occurs when the bladder is full, but this may be with much or little urine, according as the bladder is contracted or dilated.

If the urine is retained a long time in the bladder it tends to decompose and becomes ammoniacal.

CHAPTER XIV.

SKIN AND FAT.

Introduction.

The whole body is clothed internally and externally in layers of varying thickness with stratified epithelium, or rows of closely connected cells of a regular type. This forms the skin outside, the mucous membrane within, and, variously modified, the glands of all organs, the lining of the respiratory organs, and (often in a single layer) the lining of closed cavities, such as those in the brain. We have here to study the outer part of this covering known as the skin.

The **skin** subserves many purposes :—

Functions of the Skin.

1. It is a most efficient *protection* to the body. Surrounding it, like a wall to a city, it guards the more delicate parts against injuries of all kinds. Where these are frequent, the skin thickens to protect the part more perfectly.

2. In it the whole *beauty* of the animal resides. Physical beauty is a physiological attribute of no small value in connection with sexual selection.

3. It is an organ of *respiration*. It breathes in O and expires CO_2; the amount of the latter being about $\frac{1}{150}$ of the amount exhaled by the lungs.

4. It is an organ of *excretion*. By means of the pores a large amount of watery vapour and used-up animal matter passes off daily.

5. It is an organ of *secretion*. By means of the sebaceous glands it secretes wax and other oily materials.

6. It contains the organs of *touch* and common *sensation*.

7. It is the great *heat regulator* of the body.
8. It has some *absorbent* powers.
9. Its outer layer has a special power of *preventing evaporation.*

Structure of the Skin.

The skin consists of two distinct layers. The upper one is known as the *epidermis*, or scarf or false skin; the lower as the *corium*, or *cutis vera*, or *derma*, or true skin.

The **epidermis** contains neither blood-vessels nor

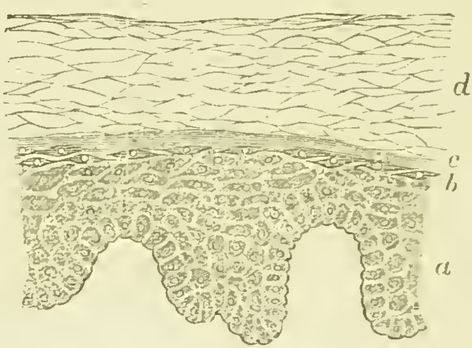


Fig. 109.—From a Vertical Section through the Epidermis.
a, The stratum Malpighii, or columnar cells; *b*, the stratum granulosum, or prickle cells; *c*, the stratum lucidum; *d*, the stratum corneum, or flattened cells.

The Epidermis.

nerves, and consists entirely of a mass of cells. It may be subdivided into two parts, the outer horny part or *cuticle*, consisting of rows of more or less flattened cells; and the inner or *rete mucosum*, which forms the *rete Malpighi*, which is composed in the upper parts of ridge and furrow or prickle cells, and in the lower (next the true skin) of cells more or less columnar.

Functions of Epidermis Cells.

The cells of the scarf skin have two functions. The lowest layer makes and stores up in the nucleus and body of each cell, *pigment* of various shades, from straw to black, according to the colour of the person; all the colour of the skin being formed by the cells in this Malpighian layer.

The cells of the cuticle manufacture, largely out of their own semi-dried protoplasm, a horny substance called *keratin*, that forms the substance of nails, the covering of the hair, and gives firmness to the skin.

The thickness of this epidermis varies greatly. In the palms of the hands and soles of the feet it is very thick, and its yellow horny layers entirely obscure the colour of the flesh underneath. Pressure and irritation cause active

Fig. 110.—Two Tactile Papillæ of the Skin, freed of Epithelium.

cell growth, so that it thickens rapidly, and we get horny hands and corns. On the cheek it is very thin, and the blood-vessels in the true skin can be clearly seen.

The Cutis vera.

The **true skin** underneath is separated from the scarf skin by a fine basement membrane across which all the nourishment from the blood to the epidermis has to pass.

Papillæ.

The surface of the *cutis vera* is raised into papillæ or conical elevations, which constitute the organ of touch. In the depressions between them the epidermis is, of course, much thicker. They will be described

later on. The skin itself is formed of bundles of mixed fibrous and elastic tissue crossing in all directions and forming spaces or areolæ, in which large numbers of fat cells lie.

Plain muscle fibres, numerous blood-vessels, and sensory nerves are found in it.

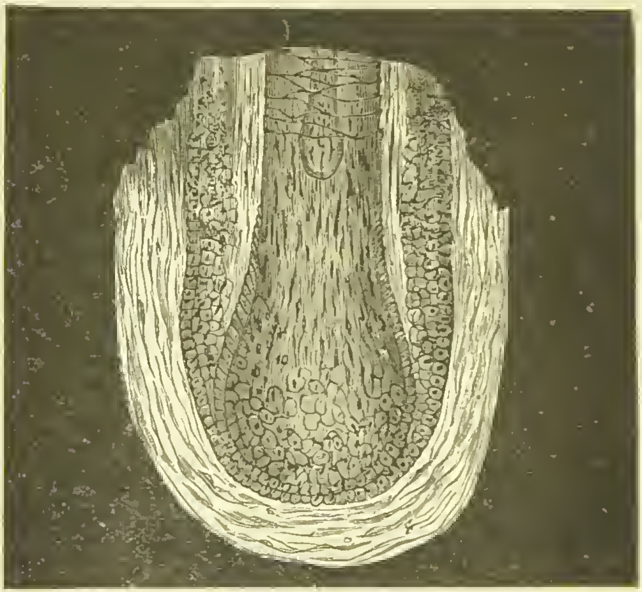


Fig. 111.—Root of Hair, with surrounding Epidermal Cells.

The cutis vera is tough and elastic and lies upon a basis of adipose and connective tissue, the fat layer below being from a quarter of an inch to two or three inches thick, according to the locality and the structure of the person.

Fat Layer.

In some parts of the body, as in the eyelids, no subcutaneous fat is ever formed.

The hair and nails are specially modified outgrowths of the epidermis.

Each **hair** grows out of a follicle or pit, which is really an indentation of the skin, generally deeper than the sweat glands, passing right through the skin into the subcutaneous tissue. It has a bulbous extremity and is lined with epidermis. At the bottom a small papilla of the cutis vera rises up, clothed with epidermis, and it is the growth of this that forms the hair, which gradually emerges from the follicle. Its outer layer consists of epidermal cells, arranged in the form of imbricated scales with the edges turned upwards. Beneath this is the

Structure of a Hair.

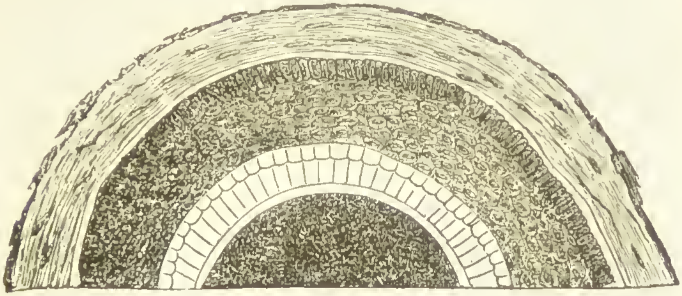


Fig. 112.—Transverse Section of a Human Hair from the head, with its Follicle.

general horny layer, which often forms the whole of the rest of the hair. Sometimes in the middle there is a pith, or medulla, composed of irregular cells, fat, and often air.

As this hair closely fits the follicle, the epidermis at the side of it is closely moulded on the scaly exterior ; so that when a hair is plucked out "by the roots" the epidermal layer of the follicle or "root sheath" is carried away with it.

The *hair follicle* lies obliquely to the surface of the skin, and generally has the mouths of one or two sebaceous glands opening on to the sides of the hair in it. In section, a hair follicle presents, from without inward, the irregular connective tissue of the true skin, the clear basement

membrane of the epidermis; then we get the outer root sheath (corresponding to the lower part of the epidermis), and then the inner root sheath, which retains its horny character as far down as the opening of the sebaceous glands.


Fig. 113.—Root and Shaft of Hair.

The *arrector pili* muscle is a layer of smooth muscle fibre that stretches downwards obliquely from the true skin to the bulb of the hair, which it embraces. When it contracts therefore it erects the hair and produces goose-skin. At the same time it compresses the sebaceous gland. Hair is *elastic*, stretching to one-third of its length; it is *strong*, four human hairs carrying 1 lb. It resists putrefaction a long time, and is highly hygroscopic. It grows by proliferation of epidermal cells from below. At a certain period the bulb dies, and the hair falls off, leaving a fresh papilla behind and a new hair. Hair becomes *grey* from loss of colour in the cells. It is *silvery* when air bubbles enter the medulla and refract the light. Hair covers the whole skin except the palms and soles, the greater part of the

fingers and toes, the surface of the eyelids, and parts of the genital organs. Hairs generally radiate from centres, in the head generally from one. The hairs of the head number about 100,000. Straight hair is round, and curly hair more or less oval.

In animals, of course, hair is a covering, in man it is mainly an ornament.

Fig. 114.—Two Hairs, showing Root, Sebaceous Glands at sides of Shaft, and the Arrector Pili Muscles.

The Nails.

The **nails**, like the hair, are an epidermal outgrowth to give firmness to the soft tips of the fingers. They are composed of flat, horny cells, and grow out of a shallow groove in the corium called the *matrix*. The nail lies on a bed of the skin that is raised in regular ridges, forming grooves on the under surface of the nail. As the cells grow beneath and at the matrix they make the nail thicker and longer, and keep pushing it along the bed towards the tip of the finger. As the fresh layers of cells keep being added, from the bed as far as the lunula or

half-moon, the nail is thinnest at the matrix and thickens as far as the lunula, whence it continues the same thickness to the tip.

Glands of the Skin.

The **glands** of the skin are two in number—*sudoriparous* and *sebaceous*, the one excretory, the other secretory.

Sudoriparous or **Sweat glands**, or pores, consist of a long blind tube which opens at one end by an oblique valve-like mouth on the surface (at other times it is wide and trumpet-shaped). From this the tube descends in a spiral through the skin into the areolar tissue beneath, and here

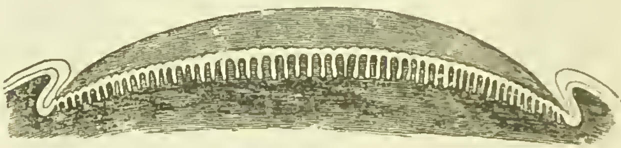


Fig. 115.—Nail and Matrix in Transverse Section.

the blind extremity is coiled up. The glands are numerous and large in the palm, sole, forehead, and sides of the nose. In the axilla they form a complete layer.

They are few on the back and they are absent from parts of the genitals and the lips. The ceruminous glands of the ear, though they secrete wax, are much like sweat glands. The whole tube consists of a basement membrane lined with cells. The canal consists of several layers of columnar cells having a small central tube. The coiled part of the tube is lined by a single layer of tall, or a double layer of short, cylindrical cells, often containing oil globules. A network of capillaries and also of arteries (which break up into a *rete mirabile* and reunite) surround the coils, also a plexus of nerves. The total number of sweat glands is about two and a half millions. These

glands, besides secreting sweat, have a limited power of respiration.

Sweat.

Sweat is a turbid, colourless, acid (alkaline when fresh), saltish fluid with a peculiar odour, and is excreted at the rate of about 2 lbs. a day. It has the following composition :—

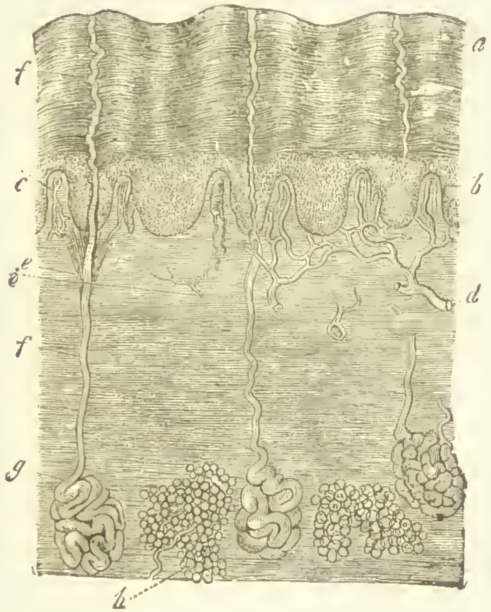


Fig. 116.—Human Skin in Vertical Section, showing

a, Epidermis; *b*, Papillæ; *c*, Nerve Bulb; *d*, Blood-vessels; *e*, True Skin; *f*, Sweat Duct; *g*, Sweat Gland; *h*, Adipose Tissue; *i*, Nerve Fibre.

Water	99·5
Organic Acids	·1
Salts—Sodium Chloride	·1
Fats—Cholesterin	·1
Extractives and Epithelium	·2
	100·0

If secreted slowly it is evaporated and not perceived: this is *transpiration*, or insensible perspiration. If more rapidly, it collects in drops, and is called *perspiration*. As

a rule, the right side perspires more than the left. The palms secrete most, then the soles. The amount varies inversely with the quantity of urine. Certain drugs taken in sufficient quantity, such as arsenic and mercury, are excreted in the sweat.

The excretion of water by the skin is double the amount excreted by the lungs, and averages $\frac{1}{67}$th of the body weight. It is *increased* by heat; by a watery condition of the blood, as after copious water-drinking; by increased body activity; by certain drugs, such as pilocarpin, ammonia, etc.; and lastly, by nerve action. Cold, copious urination as in diabetes, rest of body, drugs such as morphia in large doses, and direct nerve action, *diminish* or arrest it.

The secretion is controlled by the sympathetic system and centred in the spine and medulla. As a rule, as in saliva, the secretory and vaso-motor centres act together, so that there is a large supply of blood. But the contrary may occur, and profuse perspiration arise from the secreting centre acting alone, so that the skin is pale and the circulation feeble. The sweat centre may be excited directly by drugs, overheating, or by very venous blood. The controlling sweat centre is in the medulla. When this is stimulated in a cat, all paws freely sweat, even three-quarters of an hour after death. In certain diseases (rheumatic fever, etc.) sweat is greatly increased, in others it is diminished.

Nerve Control.

The sudoriparous glands also respire. An arm shut in an air-tight box expires enough CO_2 to put out a candle if introduced after an hour. In frogs and other cold-blooded animals, two-thirds of the CO_2 is excreted through the skin, which is thus more important than the lungs. Varnishing the skin in man does not cause death by stopping this function or by checking the sweat, but by lowering the temperature, which falls

Respiration.

rapidly to 40° F. if the whole surface is varnished. Rabbits die when only one-eighth of their skin is varnished.

Sebaceous Glands.

The **sebaceous glands** are most numerous where there is most hair, as in the scalp and face, and also at the various openings into the body. There are none in the palms or soles. They are simple, lobulated glands lined with cubical cells filled with fat globules. It is the breaking up of these cells that form the *sebum*, which is a white ointment, and is discharged by the duct on the surface by the side of a hair, or into the hair follicle itself.

It is composed of oily extracts and stearin. The wax of the ear is a compound of this with the bitter cerumen discharged by the sudoriparous glands there. Sebum keeps the skin supple and from becoming sodden by the quantity of water excreted, and the hair from being too dry.

Subcutaneous Fat.

The **subcutaneous fat** acts as an efficient protection, filling up hollows and covering projecting parts. It forms an admirable elastic pad, and, being a bad conductor of heat, preserves the temperature of the body. The firm, elastic skin over this preserves the body still further from injury, while the dry, horny epidermis prevents the absorption of poison or the drying of the tissues beneath (as is seen when it is removed after death). It also prevents adjoining surfaces from growing together.

We will consider the skin as a heat regulator in another chapter.

Absorbent Powers of the Skin.

As an absorbent its powers are slight. Ointments can be rubbed in and absorbed where the skin is thin, and so can mercury. If the epidermis be removed the surface absorbs rapidly.

Water is absorbed slightly when in a bath, especially if the amount of fluid in the body be deficient, but no nourishment (such as milk) can be absorbed by the skin in appreciable quantities.

CHAPTER XV.

MUSCLES.

Most forms of motion in the body and all forms of locomotion are performed by contractile tissue, of which muscle forms the chief part.

Introduction.

Colourless corpuscles and ciliated cells are forms of contractile tissue that we shall consider elsewhere.

I. STRUCTURE OF MUSCLE.

Muscles, Striped and Smooth.

Muscles may be broadly divided into two varieties:—(1) The *striped*, or striated, also called voluntary, because they are with one exception under the control of the will; and (2) The *unstriped*, smooth, or involuntary, so called because they are not under the control of the will, their action being reflex or automatic, so that we are not as a rule conscious of it.

Qualities of Striped and Smooth Muscles.

The action or contraction of the *striped muscles* controlled by the cerebro-spinal system is quick, decided, and simultaneous in all parts of the muscle. That of the *unstriped*, on the contrary, controlled by the sympathetic system, is slow, gradual, and spreads like a wave from one part of the muscle to another in a manner called *vermicular*.

Striped Muscles for Active Movements, Smooth for Passive Vegetative Life.

All the skeletal muscles (including those attached to bones, those of the tongue, pharynx, eye, ear, urethra, external anal sphincter, and diaphragm) are *striped* and voluntary. Most of those connected with the organs of digestion, circulation, respiration and secretion are *unstriped* and involuntary.

The **heart** muscle occupies an intermediate position between the two. On the one hand it is striped, and the movement is decisive and simultaneous; on the other hand, the fibres are branched and without investing sheath, and not under the control of the will.

Heart Muscle.

We will first describe the striped muscles and their functions, and afterwards the smooth.

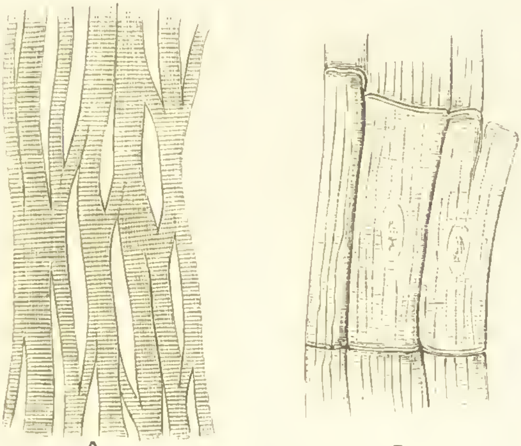


Fig. 117.—Fibres of Heart Muscle.
A, Under low power; B, under high power.

The whole mass of striped muscles form about two-fifths of the body weight. There are some 250 pairs of skeletal muscles and only about five single ones.

Number of Muscles.

Each separate muscle is covered by a fine sheath of connective tissue called the *fascia*, and is attached at each end (generally to bone) either directly by the fibres, which is rare, or by a stout fibrous band called a *tendon*, or by a broad fibrous membrane called an *aponeurosis*. The muscle being thus fixed at both

Muscle Described.

ends (one or both of which must be movable), and being capable of contraction, causes movements by the approximation of its two ends.

The muscle itself is closely covered with a fine layer of connective tissue (*perimysium*), which also divides it into bundles of fibres (*fasciculi*). In each bundle every separate fibre is separated by very delicate tissue (*endomysium*). The tendon is partly formed by the blending of all these sheaths. In some cases the muscle fibres themselves are directly connected to the tendon or aponeurosis where they end. A muscle fibre is $\frac{1}{600}$ inch thick, and from $\frac{1}{4}$ to $1\frac{1}{2}$ inches long. In short muscles the fibres stretch all the length; in longer ones they are connected (or spliced) together end to end. They lie perfectly parallel and never branch, save in the heart. Each fibre consists of at least three parts:—(1) An investing sheath called *sarcolemma*, in which nuclei are seen at intervals; (2) The *sarcous* or protoplasmic substance that composes the various parts of the fibre; and (3) The *connecting* material that unites them together.

Muscle Fibre.

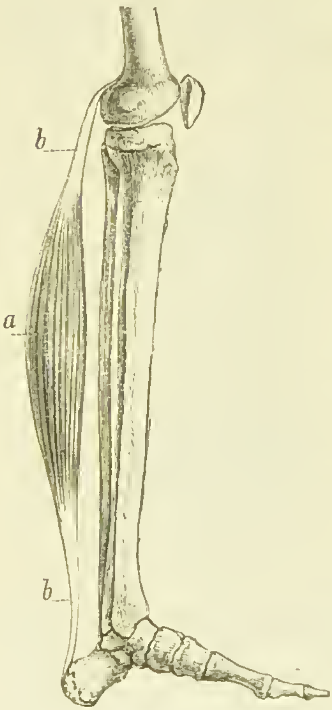


Fig. 118.—Muscle and Tendon. *a*, Muscle; *b*, tendons.

Structure of a Fibre.

Sarcolemma is an elastic connective tissue. The heart fibres are without it.

The **sarcous substance** within is semi-fluid, trans-

parent, viscid, and banded with alternate dark and light bars that give it the striped appearance. The sarcolemma is not striped. Small fat cells lie at intervals between the fibres, which greatly increase in disease.

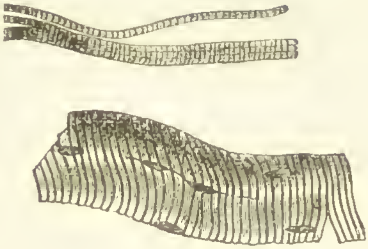


Fig. 119.—Muscle Fibres.

If a fibre be treated with alcohol or bichromate of potash it breaks up longitudinally into individual fibrils; if it be treated with dilute HCl, it separates transversely in regular discs, like a pile of coins. The fibrillar division is the commoner. The transverse bands on each fibril, light and dark, are of about the same width.

Fibrils.

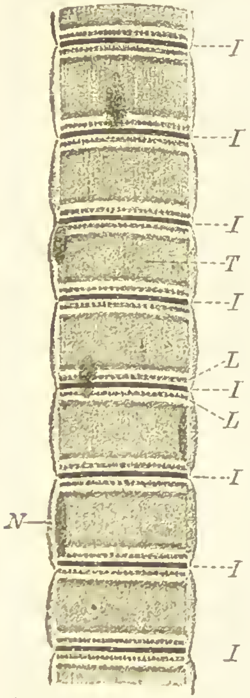


Fig. 120.—Muscular Fibre, stained with hæmatoxylin, of Staphylinus cæsareus. (Rollett.)

I, Intermediate disc (Krause's membrane); L, secondary disc (placed within the lateral disc); T, transverse disc (sarcous elements); N, nucleus of muscle-corpuscle.

Looked at more closely, a dark line is seen dividing the light band into two. This is now proved to be a thin membrane (*Krause's*) joining the sarcolemma at each side, thus dividing the fibre into a number of compartments, with a broad dark band in the centre and a narrow bright one at each side. The dark band seen by polarised light is found to be *anisotropic*, or *doubly refracting:* the light, *isotropic*, or *singly refracting;* and the *dark band is generally believed to be the contractile part.* The ultimate construction of the fibrils is a matter of theory.

Dark and Light Bands.

Bowman's represents them as built up of "sarcous elements" or rectangular bodies, like oblong beads, longer than they are broad, each composed of one dark central and two bright end discs. Schäfer believes each segment between Krause's Membrane is composed of tiny rods, side by side, ending in a row of small granules that is seen along the margin of the light discs. A light band (Hensen's) observed in the middle of the dark central band is explained by the rods being thicker at the ends than in the centre.

Bowman's Theory.

Schäfer's Theory.

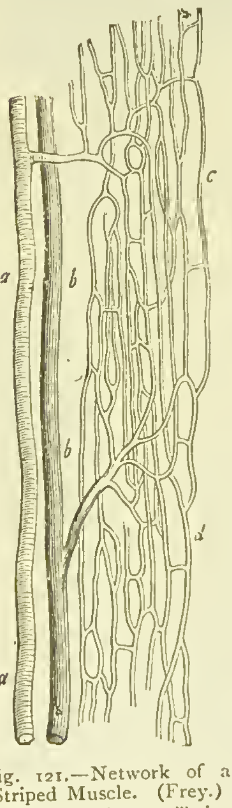


Fig. 121.—Network of a Striped Muscle. (Frey.) *a*, Artery; *b*, vein; *c*, capillaries.

Many of the appearances described are believed to be post-mortem changes. For instance, many believe that in life the whole fibre is isotropic.

The muscle fibres have an abundant blood supply, not from one, but several arteries; the capillaries lying longitudinally between them, but never penetrating the sarcolemma, through which, therefore, the fibre must receive its nourishment. Numerous lymphatics run between the fibres.

Blood Supply.

Sensory nerves end on the outer surface of the sarcolemma and give the feeling to the muscle known as *muscle-sense.*

Nerves.

Some fibres and muscles are pale, most are red. The red contain hæmoglobin, the others do not. The motor nerves are distributed to each separate fibre. As there are, however, not so many nerves as fibres, one may have to supply thirty, which it does by subdividing.

Parts of some muscles, however, receive no nerves at all, as the lower end of the sartorius in frogs.

The nerve terminates under the sarcolemma, about midway in the length of each fibre, in a *motor end-plate*, which is a mass of protoplasm and is often connected with the nucleus of the sarcolemma.

Muscle generally has the following composition :—

Chemical Composition.

Water	75·0
Nitrogenous bodies, myosinogen, musculine, alkali and serum (albumen, creatin, and traces of other extractives), urea, xanthin, taurin, etc.	20·0
Non-nitrogenous bodies, glycogen (in heart muscle), inosite, fat	1·0
Salts, mostly potassium phosphate ...	4·0
Hæmoglobin	
Gas—CO_2 in combination	
Ferment—pepsin, a starch, and a lactic acid ferment	
	100·0

Fresh muscle is alkaline or neutral. If it be frozen to $-10°$ C. it becomes like wax. Pounded in a frozen mortar it is like snow (muscle snow). Raised to $-3°$ C. it melts into a yellow syrup (muscle juice, or plasma), while at 40° C. it coagulates into a soft clot and yields an *acid* serum. The clot is formed (from the *myosinogen* in the living muscle) of *myosin*, a globulin akin to fibrin, which, with acid, form *syntonin* or *acid albumen*. The acid in the serum is *sarcolactic*. Myosin differs from fibrin in that it can be dissolved and re-coagulated. The clotting can be assisted and retarded by the same means as a blood-clot.

Experiments.

Musculine only differs from albumen in being coagulated at 45° C.

Inosite is a body which has the composition but not the properties of sugar.

2. PHENOMENA OF MUSCLE.

We will now consider muscle under four conditions: *rest*, *work*, *fatigue*, and *death*:—

Muscle at rest is (*a*) neutral or alkaline—(*b*) absorbs O

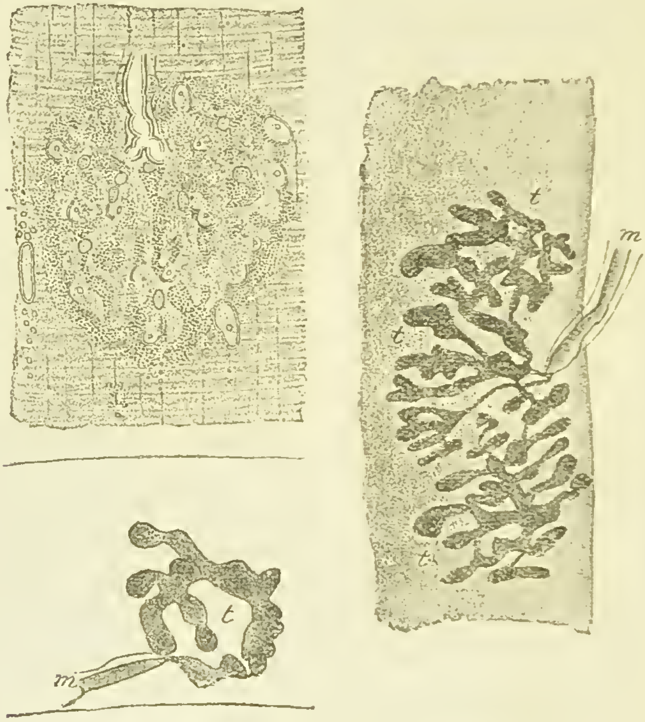


Fig. 122.—Motor End Plates of Nerves in Striped Muscle. *m*, Nerve; *t*, end plate.

and gives off CO_2—(*c*) has slight but perfect elasticity—(*d*) is irritable—(*e*) is always slightly stretched in the body (to save waste of force)—(*f*) is always subject to nitrogenous change (waste and repair ever going on)—(*g*) shows, with a delicate galvanometer, certain electric currents.

Muscle at Rest.

These are best seen in the *rheoscopic* frog. The

muscles of two frogs with nerves attached are prepared, and the nerve of one is allowed to touch the muscle of the other in two places. The "currents of rest" in the muscle being thus conveyed along the nerve to the other muscle cause it to contract. These currents were believed by Du Bois Reymond to be proof of the electromotive nature of the sarcous elements, but are now ascertained to be only on the surface, of artificial origin, and probably due to post-mortem changes.

Nerve Currents.

The irritability of muscle is a wide-spread property of protoplasm, and exists, as we have seen, in leucocytes and cilia. Where it exerts its force in a definite direction it is called *contractility*. This property is inherent in the muscle fibre itself, and is not imparted to it by the nerve :—

Irritability.

1. Because it exists in parts where no nerves are found, *e.g.* the lower end of the sartorius in frogs.

2. It persists after the nerve is divided.

3. It is found in the fœtal heart before the nerve structure is formed.

4. If the motor end-plate (not the nerve-trunk) is poisoned by curari the muscle will still contract under direct stimuli.

5. Ammonia and carbolic acid cause no contraction if applied to the nerve, but do if applied to the muscle; on the other hand, glycerin stimulates the nerve, and not the muscle.

Muscle at work receives more blood and the capillaries are dilated.

(*a*) It has an acid reaction, due to sarcolactic acid.

(*b*) It absorbs more O (there being more O breathed when we are work and less found in the veins).

Muscle at Work.

(*c*) It excretes more CO_2 (there being more expired when we are at work and more found in the veins).

(*d*) The amount of glycogen decreases ; but muscle can contract without any.

(*e*) There is no increase of *kreatin.*

(*f*) The amount of urea *is not affected* by muscle work.

(*g*) Heat is formed during muscle contraction in the proportion of about $\frac{9}{10}$ of heat to $\frac{1}{10}$ of work. The body is thus very little more economical than a steam-engine, in which nearly $\frac{1}{10}$ is work and $\frac{9}{10}$ heat, only in the human machine the heat is of great use to warm the body.

(*h*) The contraction forms a musical sound.

(*j*) Negative electric currents are set up by muscle in action.

(*k*) It also slightly decreases in volume (about $\frac{1}{1000}$ part).

(*l*) Lastly, when at work it contracts.

Its irritability may be thus excited by direct or indirect stimuli :—

Contraction.

Directly, by chemical means—most acids and the salts of many metals (iron, copper, zinc, etc.) ;

By thermal means—moderate heat ;

By mechanical means—a blow on the muscle ;

By electrical means, as by the making or breaking of an induction circuit ;

Or *indirectly*, through the motor nerve attached.

The contraction changes the form, making it shorter and thicker, but does not perceptibly alter the bulk.

Changes in Contraction.

We cannot really trace the means by which the change of form is affected, nor the relation between *striation* and *contraction.* From the diminution of glycogen, and the absence of any increase in nitrogen products, it is believed to be due to the explosion (not direct oxidation) of a hydrocarbon compound, but, after all, it *may contract at the expense of the proteids.* Certain

changes take place during contraction in the appearance of the dark and light bands. As contraction begins the distinction between the two becomes less marked; the whole sarcous element then becomes uniformly grey; and lastly, it becomes nearly as broad as it was long, and light instead of dark in the middle, with a dark band at each end. It thus appears that in contraction in each sarcous element or bead the dark and light bands *change places.*

Changes in Fibre.

It is also believed by Bowman that the shortening and broadening of the bead is produced by a rearrangement of its molecules. If, for instance, there are 100 in 20 rows of 5 molecules, and these are suddenly changed into 5 rows of 20 molecules, the long and narrow form of muscle at rest becomes the short and broad form of contracted muscle.

The sarcolemma bulges between each Krause's membrane as the contents thus get broader. Some think that this is only a passive movement, and that the actively contractile part is not in the sarcous material but the elastic interfibrillar substance. The ultimate process is still *but a theory* and requires clearing up. No connection is known between the striated appearance and the speed and decision of the movement.

This change of muscle form is graphically shown by a *Myograph.* That of Helmholtz consists in a lever carrying a style, attached to the end of a muscle. The lever can be weighted at pleasure; when the muscle is galvanised and contracts, the style records the movement on a smoked paper on a revolving drum. Below can be simultaneously traced the movements of a tuning-fork vibrating at a certain rate per second.

The Myograph.

The curve thus traced consists of four parts, which, allowing $\frac{1}{10}$ of a second for the contraction, are as follows :—

Muscle Curve.

1. A latent period ($\frac{1}{100}$ second) before the muscle acts.

2. The contraction, or period of increasing energy ($\frac{4}{100}$ second).

3. The relaxation, or period of decreasing energy ($\frac{5}{100}$ second).

4. Then afterwards some slight residual contractions.

Each muscle has its own characteristic curve.

Tetanus.

Muscle *can* contract $\frac{3}{5}$ of its entire length. In the body it rarely contracts more than $\frac{1}{4}$. Obstruction to motion increases the contractile power up to a certain point. The time of the most rapid voluntary contraction is ·05 second. If the stimuli succeed one

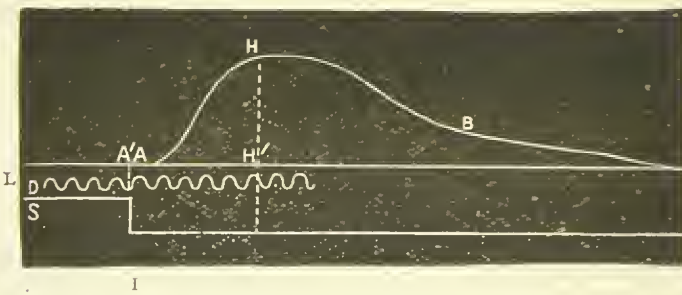


Fig. 123.—Tracing of a Single Muscular Contraction or Shock of the Muscle of a Frog. S, Line showing at I, the point where it descends, the instant at which the stimulus of the electric shock was applied to the muscle: D, tracing of the vibrations of a tuning-fork vibrating 100 times per second; L, basal line of muscle at rest; A'A, latent period of contraction; AH, period of contraction; HB, period of relaxation.

another at less intervals than $\frac{1}{10}$ second each, contraction produces a slight elevation of the curve until a maximum is reached and a condition of *tetanus* ensues. (Fig. 125.)

This was produced in a frog by 15 shocks per second, and is represented in the myograph by a wavy line. An ordinary continued voluntary contraction really consists of numerous minor vibratory contractions (shown in their maximum in shivering). The strong contraction and vibration of tetanus may be produced by disease, as in spasms, or by drugs, such as strychnine.

Muscle in fatigue is characterised (*a*) by the latent

period in the myogram being larger, (*b*) the height of the curve lower, (*c*) the contractions slower, and by (*d*) lassitude being felt. It is soon recovered from by rest, and is believed to be caused by an accumulation of the products of decomposition, which are principally phosphates. If these be removed by washing them out, or by massage, fatigue disappears much sooner.

Muscle in Fatigue.

Muscle is more rapidly fatigued than nerve. In the body

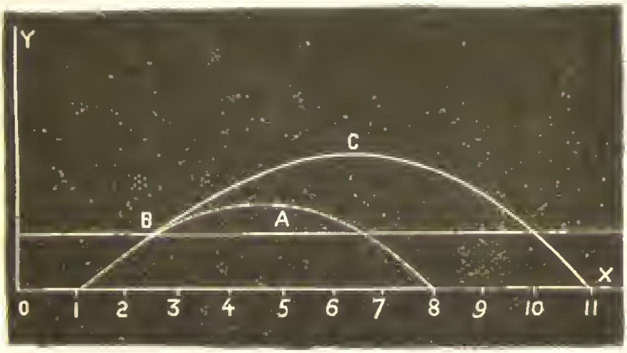


Fig. 124.—Summation of Two Stimuli.
Y, Commencement of time; A, first curve; B, application of second stimulus; C, second curve.

the will hardly ever calls forth the full muscle power; hence, although great sense of fatigue be felt after exertion, the muscle can often still be violently contracted under a strong stimulus.

Muscle in death, or *rigor mortis.* After death, generally in about six hours, but at a period varying from ten minutes to seven hours, rigidity sets in from (*a*) the coagulation of the myosin, (*b*) sarcolactic acid is formed, and (*c*) heat evolved. (*d*) The glycogen becomes grape sugar. (*e*) The muscle becomes shorter, (*f*) thicker, (*g*) opaque; (*h*) it is easily torn, (*j*) it cannot be stimulated, (*k*) all electrical reaction is abolished. (*l*) If cut, serum exudes.

Muscle in Death.

Changes in Muscle.

Rigor mortis generally begins at the jaws and passes down the body to the feet, reaching the arms last. It lasts one to six days, after which the muscle becomes soft as it gradually decomposes.

Artificial Rigor mortis.

Rigor mortis can be produced during life by stoppage of all blood supply, or by great pressure (too tight bandaging). When first setting in, it can be arrested (but not afterwards) by heat or by saturation with distilled water, and by acids. It is hastened by cold, by poisons. Rigor mortis and ordinary contraction

Fig. 125.—Incomplete Tetanus ; the undulation of the successive shocks being still perceptible.

have a certain resemblance. In both the muscle contracts, the temperature rises, and CO_2 is evolved. But in rigor mortis alone, all the electric reaction is lost, the muscle is rigid and opaque, and it cannot extend again.

Work Done.

A muscle differs from all other machines in becoming stronger the more work it does. The amount of **work done** by muscle is the product of the weight lifted and the height it is raised. If height only is the result, and no weight be raised, no work is done. In the same way, if there be only weight and no height reached, no work is done. The broader the muscle the greater weight it can lift; the longer, the greater the height

it can reach. It has greatest power when it first begins to contract.

A dynamometer conveniently measures the power of certain muscles in extension and flexion. In a frog every gramme of muscle can lift four grammemetres.

3. SMOOTH MUSCLE.

Smooth muscle differs greatly in construction from striated. It is composed of very small spindle-shaped cells, about $\frac{1}{250}$ inch long by $\frac{1}{2500}$ inch broad, with a staff-shaped nucleus. Unstriped Muscle.

The ends are taper and the cells are all cemented

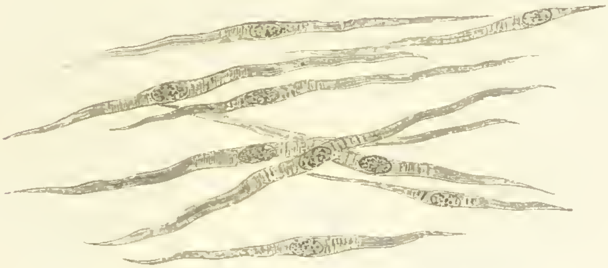


Fig. 126.—Separate Cells of Smooth Muscle.

together, but have no distinct covering of sarcolemma. They are longest in the uterus, and very short in the arteries and veins. They are plentifully supplied with blood-vessels and lymphatics. In chemical composition they resemble striped muscle. They are supplied by sympathetic nerves, mostly non-medullated, arranged in three plexuses or net-works—a *ground plexus* on the outside of the muscle bundles in the *perimysium*, an *intermediary* plexus between the bundles, and an *intermuscular* plexus between the separate cell fibres. The nerves probably end in the nucleus.

The substance of the cell is *contractile protoplasm.* In

contraction the latest period is longer, and both contraction and relaxation are slower. The contraction passes from fibre to fibre. Striped muscle not only moves all at once, but always by stimulus, rarely alone in health (in cramps and other affections it does). In plain muscle the movements are often apparently spontaneous. They are soon affected by temperature. Sometimes they pass into a fixed state of tonic contraction, which answers to the vibratory tetanic contraction of striped muscle. In some cases three or four nuclei are seen, which is a step towards the striated muscle; for both fibres are developed from single cells, only in the striated muscle a great multiplication and division of nuclei has taken place, which produces the sarcous elements or beads of which it is composed.

The body of the smooth muscle cell, like that of the striated, is believed ultimately to be a mass of fibrils.

The smooth muscles are rarely arranged in solid masses, but in sheets, and tubes, and parts of internal organs.

The only smooth muscle said to be under the control of the will is that of the iris, and this is striped in birds.

CHAPTER XVI.

MECHANISM OF THE BONES AND MUSCLES.

I. THE BONES.

Number of Bones.

THE **bones** of the body, some 200 in number in the adult, form the framework on which the body is built. The skull is formed of twenty-two bones (eight form the cranium and fourteen form the face), of which only one is movable, the others being united together by serrated edges and forming immovable joints.

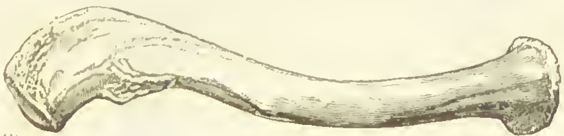


Fig. 127.—The Clavicle.

The Spine.

The head is poised on the *spinal* column, which has a double curve like a spring, and is composed of thirty-three segments, of which the last nine have become pressed together into two bones, the *sacrum* and *coccyx*, leaving twenty-four separate vertebræ, seven of which in the neck are called *cervical*; twelve in the back *dorsal*; and four in the loins *lumbar*. From the twelve dorsal vertebræ spring the twelve ribs, forming the elastic arches which, with the breastbone (*sternum*) in front, form the *thorax*. The upper seven pairs are directly united to the sternum, and are called *true* ribs; each of the next three join the ribs above,

and are called *false* ribs; while the last two are far apart and are called *floating* ribs.

Attached to the sternum above on each side are two

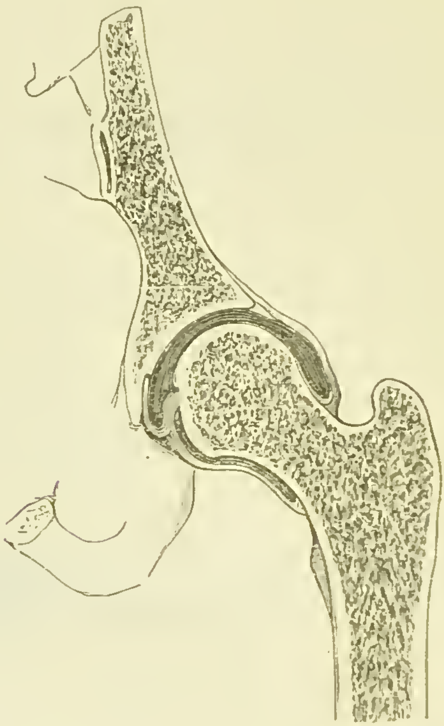


Fig. 128.—Hip Joint (Ball and Socket).

horizontal bones of a double curve, like a Roman key, called *clavicles*, which, attached at their outer extremities to two flat bones, the shoulder-blades or *scapulæ*, seem to keep the shoulders of the right width. From the scapulæ depend the arms, composed of one bone (the *humerus*) above, and two (the *radius* and *ulna*) below; the wrist and hand containing twenty-seven more.

The Arm.

Below, the sacrum which forms the base of the spine is wedged between the two hip or *innominata* bones, and

with it forms the *pelvis.* Two cup-like sockets on the outside of the pelvis receive the heads of the *femurs* or thigh bones. The leg is composed of *tibia* and *fibula*, and the foot and ankle of twenty-six bones.

The Leg.

Fig. 129.—Knee Joint (Ginglymus).

2. THE JOINTS.

These bones, themselves of four sorts—*long*, as the humerus; *short*, as the wrist bones; *flat*, as the scapulæ; and *irregular*, as the hip bones—are connected together by four varieties of movable **joints**—the *gliding* or sliding or *arthrodial* joints; the *hinge* or *ginglymus* joint; the *ball and socket* or *enarthrodial* joint; and the *ring and pivot* or *rotatory* joints.

Varieties of Bones.

And Joints.

All joints consist of two or more bones covered with cartilage, bound together with ligaments, external or internal (as in the knee), and surrounded with a fibrous capsule which is lined with a fine synovial membrane that secretes a lubricating fluid—*synovia.*

Structure of a Joint.

The *arthrodial* joints are used where slight movement with great strength is required, as in the vertebræ, and wrist and ankle joints.

Gliding Joints.

The *ginglymus* joint is used when only to-and-fro movements are required, as in the elbow.

Hinge Joints.

This hinge joint is seldom a simple to-and-fro movement. Even at the elbow the surface of the lower humerus is of a spiral shape, also the tibial surface at the ankle. The knee joint on the other hand has a flat spiral on its two surfaces, so that a certain amount of rotation takes place in flexion and tension (Fig. 129).

Ball and Socket Joints.

The *enarthrodial* joints are placed where great freedom of movement is required, as at the elbow and hips, allowing of antero-posterior, lateral, and circumductory movements at will.

The double-hinge or saddle-backed joint is used where lateral hinge movements are required as well as antero-posterior, as between the hand and fingers, so that the latter can be spread as well as flexed.

Ring and Pivot Joints.

Rotatory joints allow of rotation only, and are found between the upper two vertebræ, the atlas and axis for the rotation of the head, and at the elbow joint for the rotation of the radius that carries the hand.

Immovable joints (synarthroses) are formed for allowing the enlargement of cavities, as in the cranium.

3. THE MUSCLES.

Muscles form 45 per cent. of the weight of the body, and are used internally when hollow to surround canals, organs and vessels, either to regulate their calibre or their movements, or to close their orifices or sphincters, or for other purposes. Such muscles are mostly *unstriped.* All skeletal muscles are *striped.* These are generally fixed to two bones with a joint between. Those on the *flexor* side by shortening approximate the bones, and those on the *extensor* side by shortening separate them.

They may move one bone or both. They may form a straight band between the two, or turn an angle by passing round a pulley, as in the superior oblique muscle of the eye.

All motion of the body is performed by muscles, generally with the aid of bones.

4. THE MECHANISM OF MOVEMENT.

Motion and *locomotion* are both movements of the body, but are not the same.

Motion and Locomotion.

Motion is simply **movement.**

Locomotion is **movement from one place to another.** Walking is both motion and locomotion. Waving the arms, nodding the head, breathing—are all motions of various sorts, but are not locomotion, because the body does not change its place. As a rule, *all motion takes place by means of bones, joints, muscles, and nerves.* The *bones are moved*, the *joints are the places where they move*, the *muscles are the machinery*, and the *nerves are the power that moves them.* Now all these movements, both of motion generally and of locomotion in particular, take place according to certain fixed laws of *mechanics.*

Leverage.

The principle we are most concerned with is that of *leverage*, or movement by means of levers. A **lever** is simply a **bar that lifts**, which may be either straight or crooked, and made of any rigid substance, such as wood, iron, or bone. All our long bones are used as levers or bars.

In a lever then we consider the fulcrum, the *power, and the weight.*

Fulcrum, Power, and Weight.

The **fulcrum** *is the fixed point on which the lever moves.* The **power** *is the force that moves the lever*—the **weight** is the *object that is moved.* When you stir the coals in the grate it is very easy to see that your *arm is the power*, the *grate-bar the fulcrum*, and the *coal the weight.* In a see-saw the *heavier child is the power*, and the *lighter one is the weight*, or the one that is moved.

Three Orders of Levers.

There are three orders of levers, according to the three positions of the F, P, and W.

First Order.

In the **first order** the **fulcrum** (**F**) **is in the middle,** the *power* (P) being at one end, and the *weight* (W) at the other; thus, P, **F**, W.

Second Order.

In the **second order** the **weight** (**W**) **is in the middle,** the *fulcrum* (F) being at one end, and the *power* (P) at the other; thus, F, **W**, P.

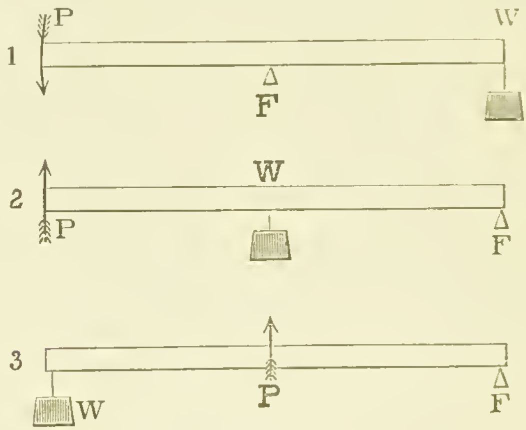


Fig. 130.—Three Orders of Levers.

Third Order.

In the **third order** the **power** (**P**) **is in the middle,** the *weight* (W) being at one end, and the *fulcrum* (F) at the other; thus, W, **P**, F.

A pair of scales and a see-saw are levers of the **first** order (P, **F**, W), and we have several examples in the body.

Examples: First Order.

When the arm is straightened at the elbow, as in boxing, the forearm is a lever of the *first* order; the elbow is F, in the middle; the triceps muscle behind is P; and the fist and forearm may be taken as W.

If you tap with the foot on the ground, the ankle joint in the middle is F, the calf-muscle fixed to the heel is P, and the ground against which the toes press is W. You raise your head when bent by a lever of the first order; the joints between the atlas and the occipital bone is F, in the

middle ; the muscles at the back of the neck that pull the head up are P, on one side ; and the front of the head and face, on the other, is W. In each of these cases you see F is between P and W.

In the **second** order (F, **W**, P) a pair of nut-crackers is a good instance. The nut, W, is in the middle ; the hinge F, at one end, and the hand squeezing, P, at the other. A man wheeling a barrow is another example. The barrow, W, is in the middle, the wheel on the ground at one end is F, the man lifting the barrow at the other is P. We get instances of this in the body. If you stand on tip-toe, W, the body, resting on the ankle, is in the middle; P, the calf-muscle, pulling up the heel at one end ; and F, the toes, resting on the ground at the other. If you support the body on the hands and bent arms, and then raise it by straightening the arms, the forearm is a lever of the second order ; the body, resting on the elbow joint, is W ; the triceps, pulling on one side of it, is P ; and the hand, pressing against the ground on the other, is F. Of course, it will be seen that in these cases one side (or arm) of the lever is *very short* (between the ankle and heel, or between the elbow and triceps), and the other *very long* (between the ankle and toes or the elbow and hand), but this does not alter the order.

Examples: Second Order.

The **third** order of levers (W, **P**, F) is that most commonly used in the body. If you take up a piece of sugar in the sugar-tongs, or of coal in the coal-tongs, you use this order. Your hand squeezing the bars in the middle is P, the hinge on one side is F, the coal or sugar on the other is W. If you tread a sewing-machine it is the same ; your foot, P, is in the middle, the hinge, F, at one end, and the rod turning the wheel, W, at the other.

Examples: Third Order.

If you place a ball or weight on your toes, and try to raise it with your heel on the ground, you have P in the

middle, or the muscles in front of the leg drawing the foot up; with F, the heel against the ground on one side, and W, the weight raised on the toes, on the other.

In the same way, if you bend your arm you have P in the middle, the biceps muscle fixed in front of the elbow; with F, the elbow, on one side, and W, the hand to be lifted, on the other.

5. THE ERECT POSITION.

The Erect Position.

The **erect position** is peculiar to man, and is not natural to any of the higher animals.

Let us consider how this position is maintained. We will begin at the foundation and go upwards. The body is balanced on the front of the feet (about three inches square), and on the two heels (about two inches square). The toes are in front of the body, and, if the body tends to fall forwards, press firmly against the ground to prevent it; and the heels behind prevent the body from falling backwards. If the body tends to fall sideways, the foot on the side towards which it leans, pressing firmly on the ground, restores the balance. In standing on one leg, of course, while there is a good deal to prevent our falling forwards, and less behind, there is little or nothing, without the other leg on the ground, to prevent our falling sideways.

The Feet.

Having the two feet then firmly planted, the two legs come next. They are hinged in the middle, at the knee, and of course would fold up backwards if not forcibly kept straight. The muscle that does this is the powerful *extensor of the leg* that, passing down the front of the thigh, crosses the front of the knee, is fixed into the kneecap, and continued down to the top of the shin in the tibia, where it ends. The knee cannot double up forwards because of the *crucial* ligament in the joint, neither can it twist to one side or another.

The Legs.

The Knee.

Now we have got the two legs upright, how are we to balance on the two balls of the hip joints the whole of the body and head above them without it falling over? Naturally, it would appear that the body would fall forward or backward unless incessantly braced up by muscles before and behind. Here, however, we come across a beautiful contrivance for saving the dreadful fatigue a muscle would undergo by such a continued effort. There is no danger of the hip joint folding up forwards in the erect position; the strain is to prevent the body, which is heavier behind, from falling backwards (Fig. 131). From the front of each hip-bone, therefore, passing across the front of each joint, and fixed just below in the front of each femur, is a *band of fibres*, the ilio-femoral band, *so strong that nothing can break or stretch it.* If we stand quite erect the whole strain is thrown off the muscles on to these powerful bands, which, when put to the full stretch, just allow the legs and body to extend in a straight line, but not more; so that the body by this means is balanced on the legs without fatigue.

The Hip Joint.

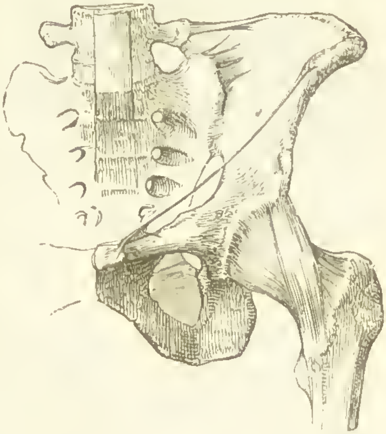


Fig. 131.—The Ligament in front of Hip Joint.

The backbone being firmly fixed on the hip-bones, is first well bent forwards to throw the weight of the heaviest part to the front, and then as it gets lighter it bends backward between the shoulders, and forward again in the neck, there being no joint that can double up between the hips and neck. At the neck a good deal of the strain of keeping the head erect is taken off by an

The Spine.

elastic ligament that, like a strong india-rubber band (Fig. 132), passes from the back of the head to the back of the spine, and keeps it naturally erect. In horses, where the strain on a muscle would be tremendous in keeping such a weight from dropping down, the head is held up by a similar band of immense strength running from the head along the nape of the neck, where it can be felt, to the shoulder. The body, therefore, tends to fall backwards below and forwards above; that is, the foot has less support at the heel behind than at the toes in front; so the ankle, the knee, and the hip would all fold up *backwards* if they could, while the head always tends to drop *forward* on the chest, as we see when we drop off to sleep in a chair.

The Elastic Ligament in the Neck.

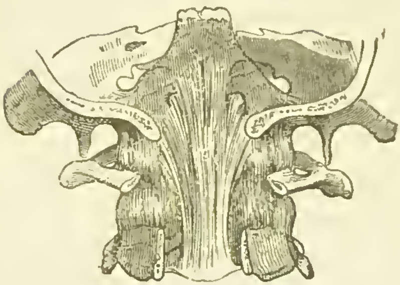


Fig. 132.—Ligaments in Neck.

6. SPRING MECHANISM OF THE BODY.

We will now consider the contrivances to preserve the brain free from all shock. In the first place, the brain does not lie on the bottom of the skull, *but floats on a sort of water-bed.* Each of the bones of the spine is separated from the next by *a thick elastic pad of cartilage* (Fig. 133). Next the spine itself is bent in a *double curve*, like a spring. The base of the spine is wedged in between the two hip bones like the key-stone of an arch, but the broad end of the base of the spine is downwards, and the narrow end of the wedge uppermost, so *the key-stone is slung* between two other bones *upside down*, and every pressure of the body and head on the base of the spine tends rather to separate the bones than to drive them together.

The femurs, *slanting across the thighs*, help next to break

the shock from passing upward; and at the knee we have between the bones *two strong pads of cartilage* to prevent all jarring.

In the foot the hinder pier of the arch comes straight down to the ground, and is formed of one bone, called the heel; but the front pier slopes very gradually, like a spring, and is composed of twenty-four bones. Thus we get in the foot-arch solidity behind and elasticity in front.

Fig. 133.—Pad of Cartilage between the Vertebræ.

7. LOCOMOTION.

The movement of the body from place to place is the result of the *combined action of many muscles.*

Locomotion.

In the **act of walking,** the muscles of the arm should be entirely relaxed, as they are not required in any way. The arms should neither be kept rigidly to the side, nor should they be swung to and fro, but left to hang naturally. Most of the other muscles are used in maintaining the position of the trunk or in moving the legs.

Walking.

In commencing to walk, say, with the left leg, the muscles of the calf raise the left heel from the ground, while the muscles in front of the abdomen pull the body a little forward, still further raising the left heel. When the body has been tilted forward a certain extent, it would fall over were it not for the next act, which consists in allowing the right leg to move forward to support it. This is done partly by a pendulum-like swing of the leg, and partly by a forward pull of the muscles in front of the thigh. The right leg is now in front of the body, and the balance is restored; but the left leg has not ceased to act yet. It continues to push the body still further forwards, while the muscles in front of the trunk still

pull it over until it is in advance of the right leg, thus raising at last the left leg off the ground, and allowing it to swing forwards in its turn. It will thus be seen that walking depends on *pushing upwards with the leg*, and *pulling forwards with the front of the trunk.* As the body is supported alternately on each leg, it is inclined a little from side to side, so as to throw the weight fully on it, and prevent falling over sideways. Thus the body, in walking, is continually rising and falling, and swaying slightly from side to side.

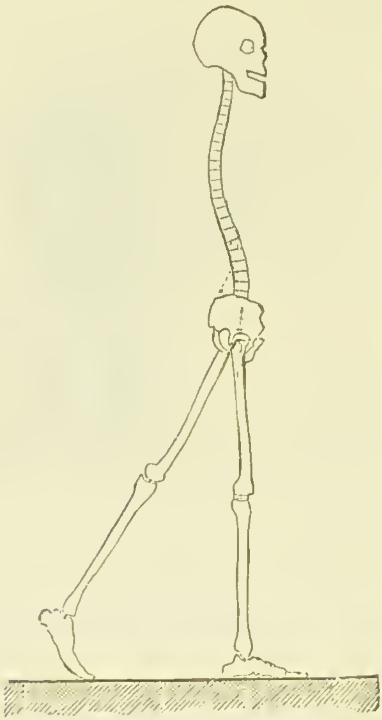


Fig. 134.—Diagram of Skeleton showing Movement in Walking.

Jumping consists of *a spring off the ground* caused by the sudden contraction of both calves, forcing the toes so violently against the ground that the body is jerked into the air.

Jumping.

Running consists in *short jumps* with each leg alternately, so that both feet are constantly off the ground at the same time. The body is inclined still more forward than in walking, as is seen in soldiers when they change to the "double" from "quick march."

Running.

Hopping consists in a jump on one leg, caused by the most violent contraction of the muscles of the calf that they are capable of, while the other leg is off the ground.

Hopping.

CHAPTER XVII.

NERVES.

I. THE TWO SYSTEMS.

NERVES may be broadly ranged in two great divisions: the *cerebro-spinal*, or those that convey impressions to and from the brain and spinal cord, of which we are more or less conscious; and the *sympathetic*, which convey impressions to and from the ganglion centres of the sympathetic system, and of which we are wholly unconscious. These two divisions often mingle, and part of the cerebro-spinal system is very closely linked, as we shall see, with the sympathetic; nevertheless the broad distinction is of value. It may further be remarked that these two divisions mainly correspond with the two great varieties of physical life.

Two Divisions.

The one, like the **vegetable**, is concerned in building up the body and storing force, or potential energy, and includes the *respiratory*, *circulating*, *digestive*, and *secreting systems*. This is supplied by the sympathetic systems, and the reflex and automatic parts of the cerebro-spinal system that resemble it in action; and its movements are almost entirely beyond the control of our wills, and even beyond our consciousness.

Nerves for Vegetative Life.

The other, which is our **animal** life proper, is concerned in the spending of force, or kinetic energy, and includes the *nerves and muscular systems*. This is supplied by the cerebro-spinal system and is almost wholly within the domain of consciousness and volition.

Nerves for Animal Life.

It may be further added, that the smooth unstriped involuntary muscles are connected with the sympathetic, and the striped voluntary muscles with the cerebro-spinal systems. To complete the distinction, the sympathetic nerves are grey and non-medullated; the cerebro-spinal white and medullated.

2. STRUCTURE OF NERVES.

Nervous structures exist in the two distinct forms of *fibres* and *cells*. **Nerve fibres** may be medullated or non-medullated. Medullated fibres are generally collected into bundles large enough to be seen by the naked eye, and these bundles into trunks.

Nerve Fibre.

A **nerve trunk** is a cord or a band varying from one-

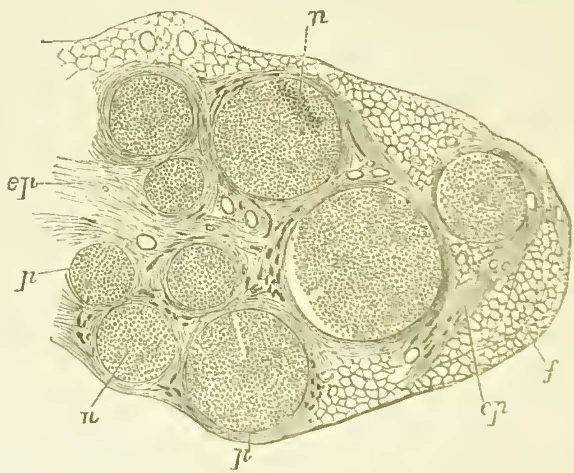


Fig. 135.—From a Transverse Section through the Sciatic Nerve of the Dog. *ep*, Epineurium; *p*, perineurium; *n*, nerve fibres constituting a nerve-bundle in cross section *f*, fat tissue surrounding the nerve.

twentieth to three-quarters inch in breadth. It is surrounded by a connective tissue sheath of *epineurium*, which contains blood-vessels and lymphatics. Each bundle that comprises it has its own special sheath of

Nerve Trunk.

perineurium—lymphatic spaces existing between the bundles ; and each nerve fibre in the bundle has its individual sheath of still finer connective tissue, called *endoneurium*. Between the fibres runs a scanty meshwork of capillaries.

Every nerve fibre runs straight from its commencement to its termination without branching or uniting with others. The bundles, of course, branch and divide and unite in

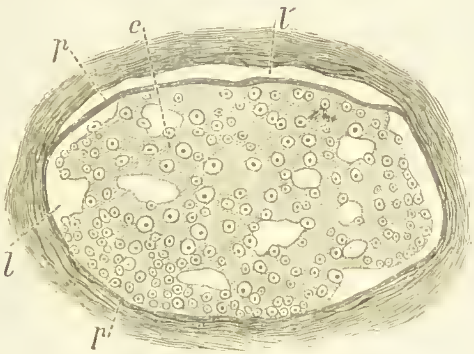


Fig. 136.—Transverse Section through a Nerve Bundle in the Tail of Mouse. *p*, The perineurium ; *e*, the endoneurium separating the medullated nerve-fibres seen in cross section ; *l'*, lymph spaces in the perineurium ; *l*, lymph spaces in the endoneurium.

plexuses, but the individual fibres never do, excepting just at their extremities.

One thirty-sixth part of the body, by weight, is composed of nerve substance.

The **medullated nerve fibre** itself varies in size from $\frac{1}{12000}$ to $\frac{1}{1500}$ inch, the smallest being in the brain, and the largest in the spinal nerves ; and it consists of three parts, the *primitive sheath*, the *medullary sheath*, and the *axis cylinder*.

Structure of Nerve Fibres.

1. The **primitive sheath,** or neurilemma, is a delicate structureless membrane, with constrictions occurring at regular intervals of about one-fifth of an inch, called the *nodes of Ranvier*. About half-way between the nodes, just under the sheath, are nerve

The Primitive Sheath.

corpuscles. In a perfectly fresh nerve neither the nodes nor the three structures of the nerve fibre are seen. The fibre is then regular in outline, with pellucid contents covered with the fine neurilemma. After a time, however, the outline becomes double, and then it gets varicose or beaded.

2. The **medullary sheath**, also known as the *white*

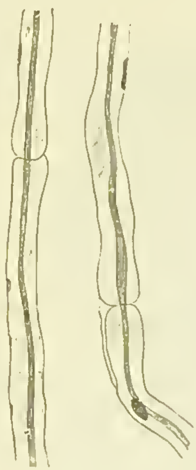


Fig. 137.—Non-Medullated Fibres.

Two Nerve Fibres, showing the nodes or constrictions of Ranvier and the axis cylinder. The medullary sheath has been dissolved away. The deeply-stained oblong nuclei indicate the nerve corpuscles within the neurilemma.

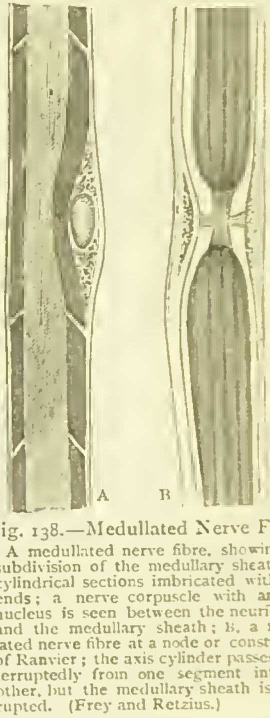


Fig. 138.—Medullated Nerve Fibres.

A, A medullated nerve fibre, showing the subdivision of the medullary sheath into cylindrical sections imbricated with their ends; a nerve corpuscle with an oval nucleus is seen between the neurilemma and the medullary sheath; B, a medullated nerve fibre at a node or constriction of Ranvier; the axis cylinder passes uninterruptedly from one segment into the other, but the medullary sheath is interrupted. (Frey and Retzius.)

substance of Schwann, gives the nerve its characteristic ivory-white appearance. It corresponds to the insulating substance round an electric wire, while the neurilemma forms the protective sheath. At the node of Ranvier it ceases, and the primitive sheath is there in contact with the axis cylinder. The medulla also serves as mechanical support and as rich prepared food for the nerve cylinder within. It is white on

The Medullary Sheath.

account of the large number of fat globules in it, which refract the light, as in chyle. It is semi-fluid and contains much cerebrin and lecithin.

The **axis cylinder** is the essential part of the nerve fibre along which the impulse travels. It occupies about one-quarter of the total breadth and lies in the centre of the fibre, and in a cut nerve often projects like the wick of a candle. It is semi-fluid and enclosed in a delicate sheath of *neuro-keratin*, and is made up of primitive fibrils, which finally separate just at its termination. The axis cylinder is really an enormously long protoplasmic process of a central "ganglion" cell. Some medullated nerves have no primitive sheath; these are found in the central white and grey matter of the nervous system.

The Axis Cylinder.

Fig. 139.—Medullated Nerve Fibres. A, B, Showing on a surface view the reticulated nature of the medullary sheath; C, two nerve fibres, showing the axis cylinder, the medullary sheath with its vertically-arranged minute rods, and the delicate neurilemma or outer hyaline sheath.

As the nerve fibre approaches its termination it first loses its medullary sheath, then the primitive sheath, the naked axis cylinder being continued until it breaks up into fibrils. In unstriped muscle the nerve divides at the node of Ranvier to form a plexus round the muscle cells.

Termination.

Non-medullated fibres are also gathered into bundles and trunks. They occur in the sympathetic system and in the olfactory and auditory nerves. All the nerves in the embryo are non-medullated. The undivided fibre consists

of axis cylinder and primitive sheath only, and varies in size from $\frac{1}{8000}$ to $\frac{1}{5000}$ inch. The absence of the white substance of Schwann gives the nerves their grey or pink appearance. Nerve corpuscles lie between the sheath and

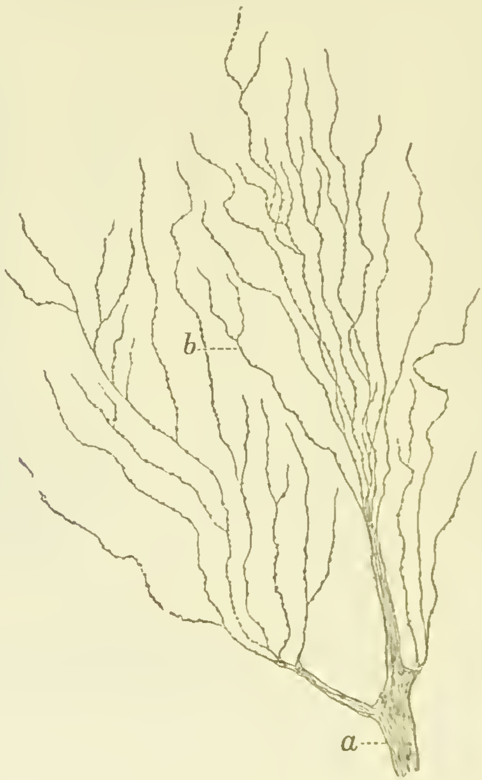


Fig. 140.—Nerve Fibres of the Cornea.

a, An axis cylinder splitting up into its constituent primitive fibrillæ near the anterior epithelium of the cornea; *b*, primitive fibrillæ.

the cylinder. These nerves differ from the medullated in branching frequently and forming networks.

Naked axis cylinders, without the primitive sheath, are also seen in the branching processes of nerve cells in the brain and spinal cord.

3. STRUCTURE OF NERVE CELLS.

Nerve Cells.

Nerve cells generally occur in clusters, called ganglia, and may be small and spherical, or caudate, or stellate. They are always nucleated and may have one, two, or more branching processes, and hence are called *unipolar*, *bipolar*, or *multipolar*; or, with no process at all, *apolar*.

Nerve Process.

One of the processes continued to an extraordinary length forms the axis cylinder of a nerve, and is directly continuous with a nucleus of the cell. This process is always unbranched, and is called the axial-cylinder process.

Fig. 141.—A small nervous branch from the sympathetic of a Mammal. (Frey.)

Ganglion Cells.

Ganglion cells are sometimes surrounded with a soft substance like the white substance of Schwann, but they have no distinct limiting membrane, and consist of finely granulated protoplasm of a fibrillated nature containing a large nucleus in a clear envelope and within it a nucleolus. They are angular with processes and are capable of motion when living.

Varieties.

Four varieties of these cells are met with:—

1. Those with no white substance of Schwann and no capsule of neurilemma, as in the brain and retina, connected with naked axis cylinder nerves.

2. Those with no white substance of Schwann, but with capsule of neurilemma, as in sympathetic ganglia, connected with the non-medullated sympathetic nerves.

3. Those with the white substance of Schwann and no capsule of neurilemma, as in the auditory nerve ganglia,

and connected with nerves of similar construction which form white substance of brain.

4. Those with both the white substance and capsule of neurilemma, as in ganglia of spinal cord, connected with ordinary medullated nerves.

Nerve cells are found in the brain and spinal cord, in ganglia, and at nerve-endings in the tissues. The spinal cells are generally unipolar, and are embedded in a finely fibrillated granular ground substance (*neuroglia*), and have no neurilemma. In the ganglia or the posterior root of the spinal nerves the nerve cells have a sheath of neurilemma and a short process which branches like a T.

The function of these cells appears principally to consist in the nutrition they afford to the nerve. They may also increase the area of nerve action, and here also non-medullated nerves are often changed into medullated. There is very little evidence that these spinal root ganglion cells possess any automatic or reflex power. All such action appears to exist in the brain and spinal cord only.

4. PROPERTIES OF NERVE MATTER.

Nerve matter has a specific gravity of 1031. It is 70 to 80 parts water, and 20 to 30 parts solids.

Chemical Analysis.

The solids are composed as follows:—

Phosphoric Acid	9·
Phosphate Potash	55·
,, Sodium	23·
,, Iron	1·
,, Calcium	2·
,, Magnesium	3·
Chloride Sodium	5·
Sulphate Potash	1·5
,, Silica	·5
	100·0

These elements are combined to form characteristic compounds, of which the chief are: *cerebrin*, *lecithin*,

protagon, *cholesterin*, and *neuro-keratin*. *Proteids*, not unlike myosin, occur chiefly in cells and axis nerve cylinder.

Cerebrin and **lecithin** are fats found in the white substance of Schwann.

Cholesterin forms about half of the white substance of Schwann.

Protagon is similar to cerebrin and forms a large part of the white substance of the brain.

Elasticity.

Nerves have no elastic tension and do not retract when cut, but they are remarkably coherent and can be greatly stretched without rupture.

Metabolism.

We know little of the metabolism of nerves. It has not been proved that in action they absorb O and expire CO_2. There is no doubt that the metabolism of the nerve centres is much more active than that of the nerves.

Stimuli.

Nerves are very excitable or irritable, as can be shown by various stimuli. Besides the normal nerve impulse, these may be mechanical, chemical, thermal, electric, etc.

Mechanical.

Mechanical stimuli produce at first in sensory nerves sensation or pain ; in motor nerves muscular movement. If continued, as in the form of long pressure, the motor nerve gets paralysed before the sensory. When a limb "sleeps" the paralysis is believed to be due to the continued pressure breaking for a time the continuity of the axis cylinder. Nerve-stretching also paralyses the irritability of a nerve for a short time.

Thermal.

Thermal stimuli. Heat and cold increase the excitability of a nerve, unless extreme, when both diminish it. Rapid changes of temperature quickly exhaust a nerve and kill it.

Chemical.

Chemical stimuli act rapidly, at first stimulating and then paralysing. Such stimuli are acids, alkalies, alcohol, ether, chloroform, etc.

Electrical stimuli act most on a nerve at the moment of application (making) or cessation (breaking). Single shocks rapidly applied so excite the motor nerves that tetanus is produced in the muscle. It is frequently found that the further a motor nerve is from the central system, and the nearer a sensory nerve is to it, the greater the effect produced by electrical stimulus.

Electrical.

The electric current produces no manifest change in the nerve fibre as it does in muscle fibre.

The nature of the **normal stimulus** is entirely unknown. It travels centrifugally giving rise to motion, or centripetally giving rise to sensation, and moves more slowly than one induced by electricity.

The nutrition of nerves depends to a great extent on the nerve cells, and their excitability depends on their nutrition. Nerve fibre gets exhausted more slowly than muscle fibre, and recovers more slowly.

Nutrition of Nerves.

Continued inaction of a nerve diminishes its excitability. If any nerve be severed, traumatic degeneration sets in and the irritation decreases from the cut ends upwards; the medulla and axis break up as far as the first node of Ranvier, beyond which the nerve continues healthy. Repair takes place when the severed ends are brought together from the sound parts in the reverse direction.

Degeneration.

The effects of section of a spinal nerve are very instructive. If (1) the *whole nerve* be divided after the junction of the anterior and posterior roots, complete peripheral degeneration of both sensory and motor fibres sets in: the central part remaining unaltered. (2) If the *anterior root* alone be divided, only the motor peripheral fibres connected with it degenerate, the rest of the nerve remaining sound. (3) If the *posterior root* be divided before the ganglion, the

Section of Spinal Nerve.

nerve only degenerates between the section and the spinal cord. (4) If it be divided before and after the ganglion, degeneration spreads upwards to the spinal cord and downward to the periphery. These experiments show that the centre of nutrition, or *trophic centre* of the anterior or motor root, lies in the spinal cord, probably in the cells in the anterior horn, while that of the posterior or sensory root lies in the posterior ganglion.

Nerve-electricity. Natural currents of rest exist in nerves, running in a detached piece from the centre to each end, as in muscle. Perfectly fresh uninjured nerve or muscle, or dead nerve or muscle, yields no currents. The current in the nerve flows centrifugally in a centripetal nerve, and centripetally in a centrifugal.

Nerve Currents.

Stimulation of the nerve produces *negative variation*, or diminution of the natural nerve currents.

By the "rheoscopic frog," muscle can be made to contract by the force of natural muscle currents of rest passing along a nerve. If a moist conductor be placed so as to connect the longitudinal with the transversal surface of a frog's gastrocnemius, and the sciatic nerve connected with the gastrocnemius of another leg be thrown on the conductor, the natural current in the latter muscle passing along the nerve will contract the cut muscle. The same result can be obtained if the sciatic nerve be merely laid across the cut end of the fresh gastrocnemius.

The Rheoscopic Frog.

By means of a Daniell's battery with a Du Bois Reymond key, currents can be sent through nerves at will. It is found that muscle connected with the nerve contracts at the making and breaking of the currents, while during the time of its passage a so-called polarising current is set up in the nerve, producing a condition of *electrotonus*, which increases or decreases the natural current of rest according to whether it runs in the same or a contrary direction. Of the means by which currents (of action or rest) are produced in nerves we know nothing.

Nerve and Muscle Currents.

5. SENSORY AND MOTOR NERVES.

Natural nerve impulses in sensory nerves travel about 140 feet per second; in motor 111 feet per second. Sensory and motor nerves will conduct impulses indifferently either way. The direction of the current is entirely determined by the source of the impulse, which in sensory nerves is peripheral, in motor central.

Rate of Nerve Force.

As we have seen, the effect of stimulation of a nerve depends on the manner of its ending. Theoretically a nerve can carry a current either way, but practically it can only be used in the body to convey a current in one direction, because of the nerve-ending. The passing of a nerve current is therefore shown in an afferent or sensory nerve by pain or other sensation; in an efferent or motor nerve by muscular twitching or movement. Sensation is the result of organic change in a central nerve cell, just as movement is the result of organic change in a muscle cell. The terms sensory and motor are not, however, quite accurate.

Direction of Current.

Nerve fibres are better divided into: (1) *Afferent* or centripetal; (2) *efferent* or centrifugal; and (3) *intercentral*, *i.e.* between the two nerve cells.

Three Classes.

1. The functions of *afferent* nerves are: (*a*) pain or sensation; (*b*) special sense phenomena; (*c*) reflex action.

Afferent Nerves.

In a reflex action the afferent impulse is not perceived in the nerve centres, but is received by a cell which transfers it to a centrifugal fibre, so that it results in action.

2. The functions of *efferent* nerves are: (*a*) contraction of muscle;

Efferent Nerves.

(These may act on striped, smooth, or heart muscle respectively.)

(*b*) nutrition;

(These centrifugal nerves end in the tissues, and are supposed to govern their metabolism, as in the cornea, etc. In the skin, paralysis of the nerves leads to changes in the skin, eruptions, and bed-sores of a special form, due to the loss of trophic nerve influence.)

(*c*) secretion ; (*d*) inhibition of nerve action.

(As in the slowing action of the pneumogastric over the action of the heart, the nature and mode of this action is quite unknown.)

A nerve current is never diffused into other fibres or reversed in direction along the same fibre.

3. *Intercentral* nerves serve to carry on co-ordinate movements, and to connect cells for other purposes.

Intercentral.

If afferent nerves be irritated in any part, the sensation is not only felt at the spots, but is referred to all points of distribution or origin, even if running in dead or paralysed limbs. Thus, even after amputation the pain of the nerve in an irritated stump is referred to the toes, instep, or sole of the lost foot, as well as to points of irritation. In venous diseases and hysteria, pain is referred to the periphery of the nerve, though originating in the central parts, or perhaps in a neighbouring ideal centre.

Place of Sensation.

In special sense-nerves, irritation does not produce common, but special sensation; thus a blow produces a flash of light, irritation of ear or nose—sound or smell.

Special Sensation.

Afferent or sensory nerves commence in three ways :—

1. In *Paccinian corpuscles*, little oval bodies occurring in some sympathetic and sensory nerves in the hand and foot, and in many glands, and consisting of onion-like layers of connective tissue with an enlarged nerve in the centre.

Origin of Sensory Nerves.

2. *End bulbs of Krause*, found in the reproductive organs, the skin, lips, and muscle tendon, and consisting of an enlarged medullated nerve fibre, terminating in corpuscles

of various shapes, forming a mass crowned with a capsule.

3. *Touch corpuscles*, found in the papillæ of the skin, and formed of masses of fibrous and elastic tissue with a twisted mass of nerve fibre wound round it, but containing no blood-vessels.

Motor Nerves.

Efferent or motor nerves end in striped muscle in a fine network above the end-plate and a coarser one beneath it (called the sole), and in smooth muscle in plexuses between the fibres. In tendons they end in masses of corpuscles. Other efferent nerves (trophic) end in twigs of naked fibres (as in the cornea).

Spinal Nerves.

The **spinal nerves** consist of thirty-one pairs—eight cervical, twelve dorsal, five lumbar, five sacral, and one coccygeal. They all arise from the spinal cord by the roots. The anterior or motor roots are the smaller, and arise from between the posterior and lateral columns of the cord. The posterior or sensory roots are larger and contain a ganglion. The two roots unite beyond the ganglion and form a mixed nerve.

Three Branches.

Each nerve, as a rule, divides into a dorsal or *posterior* branch distributed to the back; a somatic or *anterior* branch (the largest) distributed to the front of the body (each giving motion and sensation), and a splanchnic or *internal* branch, running to the sympathetic cords and supplying the viscera.

Effect of Section.

Section of a spinal nerve destroys motion and sensibility in the parts supplied. Section of the *anterior* root only causes paralysis of muscle supplied, but no loss of sensation. Stimulation of the peripheral cut end causes contraction of the muscle, while stimulation of the central cut end causes no pain.

Section of the *posterior* root causes loss of sensation in the parts supplied. Stimulation of the peripheral cut end

causes no effect; of the central cut end causes pain and reflex movements.

Anterior and Motor.

The *anterior roots*, in addition to supplying motion to all the voluntary muscles, also contain motor fibres for some smooth muscles of blood-vessels, bladder, &c., inhibiting vaso-motor fibres, secreting fibres, sweat fibres, and trophic fibres.

Posterior and Sensory.

The *posterior roots* contain all the nerves of common sensation, and of touch, and also convey stimuli to reflex centres.

The cranial nerves will be considered after we have examined the nerve centres.

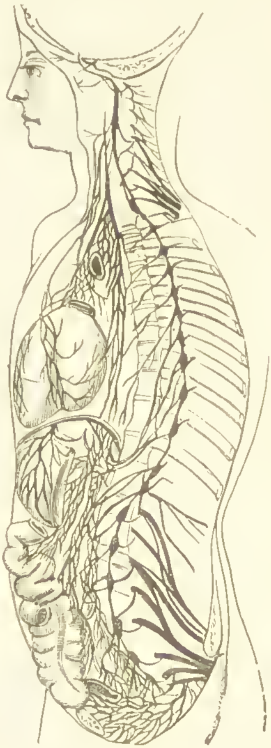


Fig. 142.—The Sympathetic Nerves.

6. SYMPATHETIC NERVES.

Sympathetic System.

The **sympathetic** nervous system consists of non-medullated nerves connected with chains of large ganglia lying on each side in front of the spine; there being three cervical, twelve dorsal, four lumbar, and five sacral. The ganglia are collected into plexuses named according to their situation, the principal being the semilunar, cœliac, renal, solar, hypogastric, and pelvic. Besides these, innumerable small ganglia exist in every part of the body. They are closely connected with the cerebral and spinal nerves. The *nerve cells* are multipolar, and each is surrounded by a capsule.

The ganglia, independent of the cerebro-spinal system,

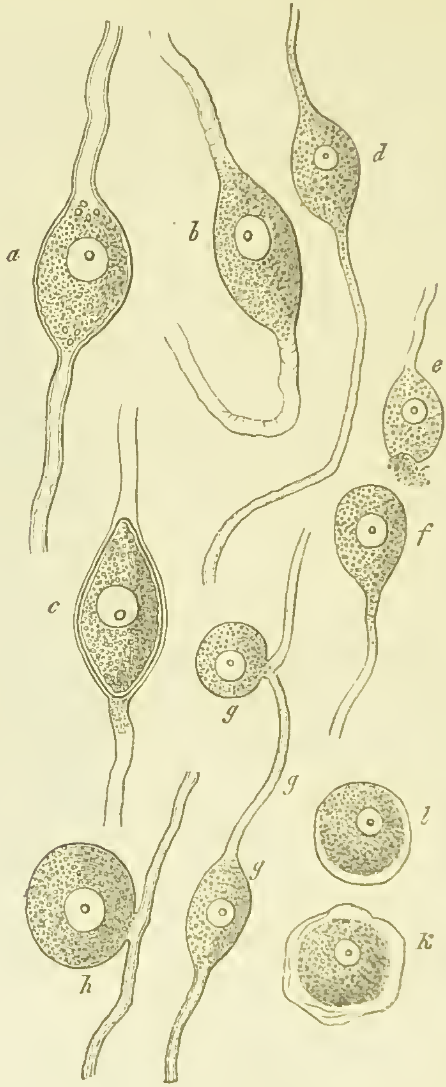


Fig. 143.—Nerve Cells from the Peripheral Sympathetic Ganglia.
k, *l*, Apolar ; *e*, *f*, unipolar ; *a*, *b*, *c*, *d*, *g*, *h*, bipolar.

are principally those in the heart, in the intestines

(*Auerbach's* and *Meissner's*), and in some parts of the reproductive system. All the other ganglia are connected with the brain, and are therefore dependent partly for their action on impulses proceeding from it, though these are of a non-voluntary, reflex, or automatic nature.

Functions.

The chief functions of the sympathetic system are (1) the movement of the various viscera; (2) the dilatation of the pupil; (3) vaso-motor functions; (4) secreting functions, including the secretion of all the digestive fluids; (5) excreting functions, as of sweat; (6) and probably trophic fibres from the viscera. In short, they comprise, as we have seen already, most of the functions of passive or vegetative physical life that are concerned in building up the life force by the process of digestion, circulation, secretion, and respiration.

CHAPTER XVIII.

NERVE CENTRES: I.—THE SPINAL CORD.

I. THE SPINAL CORD.

Nerve Centres.

THE *brain* and *spinal cord*, together with the ganglia of the sympathetic system, constitute the nerve centres of the body, and are essentially distinguished from mere aggregations of nerves by the presence of *cells and grey matter*. These centres constitute what we have termed the *engine* or motor-power of the body; that, being abundantly supplied with healthy blood, generates the force which, when liberated by the action of the mind or will, displays itself in the various phenomena of animal life, by nerves and muscles, as kinetic energy. These centres contain, as we shall see, in addition to the grey matter, vast numbers of nerve fibres as well as nerve cells of all varieties.

The Battery and Wires.

Nerve cells form the battery of the vital force; and nerves, which are originally prolongations of their processes, are the wires or conductors of this force.

Three Classes.

Nerve centres or groups of cells in the brain may be divided into at least three great classes :—

Ideal or **mental**, or those in which the *mind* and *brain* are alone in action.

Psychic, or those in which *mind*, *brain* and *body* act; and

Involuntary,* or those in which *brain* and *body* alone

* The word "involuntary" is used here to include all automatic and all reflex involuntary nerve action.

act. This last class performs many functions, but all are independent of the mind or will. The following are the chief functions of the involuntary nerve centres :—

Involuntary Functions.

a. Pure **reflection.** For this function three things are needed : an *afferent* nerve, an *efferent* nerve, and a *central* nerve cell, so that an impulse arriving along an afferent nerve, say of pain in the abdomen, is reflected back along the efferent nerve of motion that contracts the muscles of the part.

b. **Automatism.** The origination of impulses without any apparent external stimulus at all.

c. **Augmentation,** or the power of increasing nerve force by passing through the cells.

d. **Inhibition,** or the power of checking nerve force.

e. **Conduction,** or the simple passing on of nerve force without change.

f. **Transference,** or the diffusion of nerve force to various parts of the body, as in an aching tooth which produces aching of other teeth.

g. **Trophic** functions for nerve nutrition.

Spinal Centres.

The cells in the cord consist of the lowest or reflex class only ; and nerve centres in the spinal cord have at least four of these functions, viz. *reflection*, *conduction*, *transference*, and *trophic.* The spinal cord, which we shall proceed first to consider,

Fig. 144.—The Brain and Spinal Cord.

does the larger part of its work at the bidding of the brain, to which it is generally, though not always, subservient.

2. STRUCTURE OF SPINAL CORD.

The **Spinal cord** is a somewhat flattened cylindrical cord, nearly an inch in diameter and from 15 to 18 inches long, that extends from the medulla or lowest part of the brain above, down the spinal canal until it ends below, in a slender grey thread, the *filum terminale*, in the midst of a bunch of white nerves, the *cauda equina*.

General Construction.

Fig. 145. — Medulla, Spinal Cord, and Spinal Nerve Roots.

It, as well as the brain, is essentially *tubular* in structure, and consists of a small *central canal* (expanded in the brain into chambers or ventricles) lined with a layer of columnar ciliated epithelium, and surrounded successively with *grey matter*, *white matter*, and the *membranes* of the cord.

Central Canal.

Down the middle of the anterior surface of the cord runs an open fissure, while along the posterior surface is a deeper, narrower slit, more of a septum or division than a fissure.

Fissures of Cord.

The **grey matter** is in the shape of two commas with their backs to each other, and their heads to the front, united together by a band, in the midst of which is the small neural canal of which we have spoken. The posterior septum runs right up to this grey band behind, so that the surrounding white matter which

Grey Matter.

completes the cylinder is here completely bisected ; while in front, the fissure not being so deep, leaves a connecting band of white matter in front of the grey.

The grey band, or isthmus, behind the canal is called the *posterior grey commissure*, that in front of it is the *anterior grey commissure ;* the *anterior white commissure* being, as we have seen, in front of this again.

Three Commissures.

The grey matter consists of branching nerve cells and

Fig. 146.—Section of Spinal Cord, showing white and grey matter and posterior and anterior nerve roots.

naked axis cylinders ; its grey colour being due to the almost total absence of the white substance of Schwann, while it is pinkish from the amount of blood circulating in it, which is four times as much as in the white.

Structure of Grey Matter.

The **white matter** of the cord is composed of medullated nerve fibres, fine connective tissues, and *neuroglia*, which is a supporting network of fine fibres.

White Matter.

Grey matter is 81 per cent. water, and white 68 per cent.

R

It also contains lecithin, albumen, cholesterin, and salts. Grey matter is acid in reaction ; white is neutral.

The amount of white matter in the cord increases steadily from below upwards. The grey matter

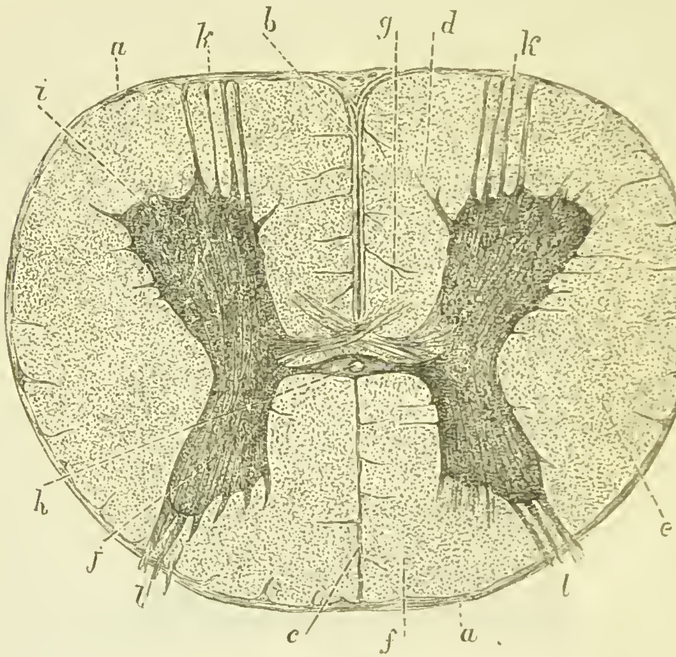


Fig. 147.—Transverse Section through the Spinal Cord of a Calf.

a, Pia mater *b*, prolongation of pia mater into the anterior longitudinal fissure; *c*, posterior longitudinal fissure ; *d*, anterior column of white matter ; *e*, lateral column of same ; *f*, posterior column of same ; *g*, anterior white commissure ; *h*, central canal ; *i*, anterior horn of grey matter ; *j*, posterior horn of grey matter ; *k*, anterior nerve roots ; *l*, posterior nerve roots.

increases suddenly at two places (the *lumbar swelling* at the twelfth dorsal vertebra, and the *cervical swelling* at the fifth cervical vertebra. The sectional area of the spinal nerves increases in like manner as the grey matter. The total area of the spinal cord just below the medulla is less than that of the spinal nerves entering it, hence, although conduction of

Amount of White and Grey Matter.

nerve fibres to and from the brain is one of its chief functions, it is evident that many nerves end in the cord itself, and closer investigation shows that not more than half the spinal nerves that enter the cord are found at its upper end. From this brief account it will be seen that the grey matter varies in size according to the number of nerves entering and leaving the part, and not according to those which are given off below it.

Membranes.

The coverings of the cord are three in number, as in the brain, and bearing the same names, though they differ in detail.

Fig. 148. — From a Transverse Section through the White Matter of the Cord.
Showing the transversely-cut medullated nerve fibres, the neuroglia between them, with two branched neuroglia cells.

Dura Mater.

The **dura mater**, a stout fibrous membrane, is but slightly attached to the vertebral canal, of which it does *not* form the periosteum as it does in the bones of the skull.

The Arachnoid.

The **arachnoid** is a serous membrane in two layers, parietal and visceral, and is separated from the pia mater by the subarachnoid space, which contains cerebro-spinal fluid.

Pia Mater.

The **pia mater** closely surrounds the cord, and is composed of fine connective tissues and blood-vessels. It sends out prolongations along each pair of spinal nerves, and dips down into the fissures of the cord.

Spinal Nerves.

The **nerves** come off (in all 31 pairs) between each pair of vertebræ, varying, however, greatly in size, and being largest at the *cervical* enlargement, where all the nerves for the upper limbs

come off; and at the *lumbar* enlargement, where those leave for the lower limbs.

The Two Roots.

The *anterior roots* leave the head or anterior horn of the grey matter by several bundles, whereas the *posterior roots* enter the tail of the comma or posterior horn in one bundle.

Anterior Efferent.

The **anterior** roots are efferent or motor, which is proved by the fact that while in section all motion in the part supplied ceases while sensation is left, stimulation of the distal end produces movement, and that of the proximal no sensation of pain.

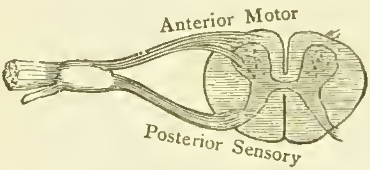


Fig. 149.—Anterior and Posterior Roots of Nerve.

Posterior Afferent.

The **posterior** roots are afferent or sensory, proved in a similar way by the fact that while in section all sensation in the part is lost while motion is left, stimulation of the distal end produces no movement, and that of the proximal end acute pain.

Spinal Column.

The white substance of the cord, consisting mainly of nerves arranged longitudinally and medullated, but without neurilemma, has been divided into various columns, which have received distinctive names. (Fig. 150.)

The **anterior columns** lie between the heart fissure on each side and the anterior roots of the spinal nerves.

The **lateral columns** lie between the anterior and posterior roots on each side; while the **posterior columns** lie between the posterior roots and the posterior fissure or septum. This last column may be subdivided into *posterior median* (next the septum), and *posterior external* (next the nerve root).

The three commissures, one white and two grey, all consist of transverse or diagonal decussating fibres.

The **anterior cornu** of the grey matter contains many large branched or multipolar cells, one process of which is

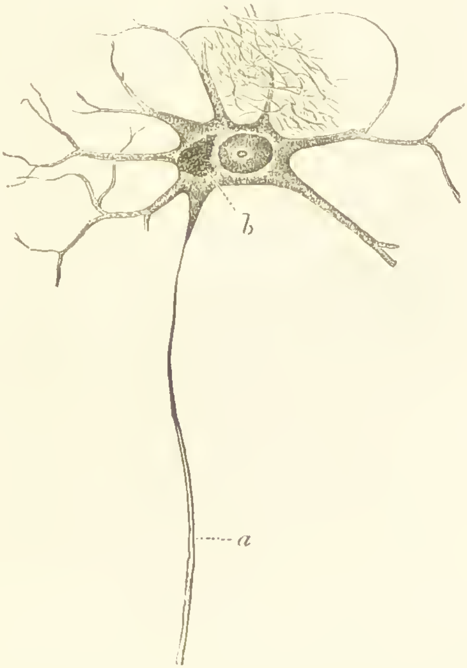


Fig. 150.—An Isolated Ganglion Cell of the Anterior Horn of the Human Cord.
a, Axis cylinder process; *b*, pigment. The branched processes of the ganglion cell break up into the fine nerve network shown in the upper part of the figure. (Gerlach, in Stricker's "Manual of Histology.")

generally continued in a nerve, while the others continue to travel until they are lost in the groundwork of fine neuroglia and nerve filaments. At the end of the **posterior cornu** is a gelatinous cap, composed principally of neuroglia, called the *substantia gelatinosa.* The cornu also contains many small cells.

Two Cornua.

Many nerve fibres in the anterior roots can be traced

from the large cells to their termination in the muscle fibre. The posterior root, on entering the cord, divides into two bundles, one of which goes to the posterior white column and the other to the substantia gelatinosa in the posterior

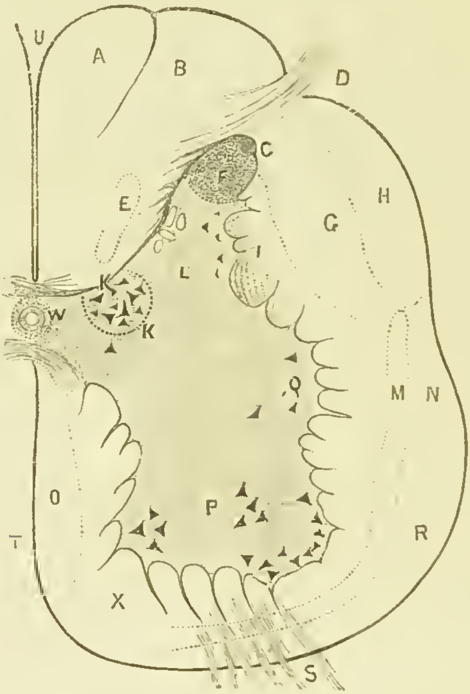


Fig. 151.—Transverse Section of a Lateral Half of Spinal Cord.

A, Posterior median column, or column of Goll; B, posterior lateral column, or column o Burdach; C, column of Lissauer; D, posterior root; E, the comma tract; F, substantia gelatinosa; G, crossed pyramidal tract; H, direct cerebellar tract; I, reticulated region of cervix cornu; K, Clarke's column; L, cervix cornu; M, Gower's descending antero-lateral tract; N, R, Gower's ascending antero lateral tract; O, direct pyramidal tract; P, anterior cornu; Q, intermedio-lateral tract; S, anterior root; T, anterior or ventral fissure; U, posterior or dorsal fissure; W, central canal; X, anterior column. The tract internal t G M is the mixed lateral column. The arrows indicate the course of the fibres.

horn. The first bundle continues right up the posterior column to the medulla.

The **nerve cells** in the cord form *four* groups. There are the larger ones in the anterior horn, the smaller in the posterior; a group in the lateral white column, and a

group along the inner edge of the posterior cornu (the posterior *vesicular column of Clarke*). This last group is discontinued in the lumbar and cervical regions.

Cells in the Cord.

While the anterior cells are directly connected with motor nerves, we must notice that such is not the case with the posterior cells, which are only indirectly connected by a thick meshwork of fibres.

The **connective tissue** of the spinal cord is very fine, and forms a delicate scaffolding around the nerves in the white matter, and covers the blood-vessels. In the grey matter especially, filling up the spaces between the intricate network of connective tissue, a particular substance is found, called neuroglia, consisting of very fine granular ground-substance composed of keratin, frequently formed into hollow cylinders in which the nerve fibrils lie.

Connective Tissue.

The course of the nerves in the spinal cord is threefold, those *ascending* to and those *descending* from the brain, or those *terminating* in the cord itself, and each of these groups is in three divisions. The fact that nerves tend to degenerate in the direction that the nerve force travels has served pathologically and physiologically to distinguish the efferent and afferent brain fibres.

Course of Nerve Fibres.

Considering the efferent or motor or **descending fibres** first, we find they run, as in the accompanying diagram, in three divisions: (*a*) the *direct or uncrossed pyramidal tract* (from the anterior pyramids in the medulla) in the anterior column; (*b*) the *crossed pyramidal tract*: and (*c*) *antero-lateral tract* in the lateral column.

Descending Tracts.

The **ascending** or sensory tracts are also in three main divisions: (*a*) The *cerebellar tract*, and (*b*) *ascending lateral tracts* in the lateral column; and (*c*) *Goll's column* in the

posterior column. Those fibres **terminating in the cord** are also in three divisions: (*a*) The *anterior ground fibres* in the anterior column: (*b*) the *mixed lateral tracts* in the lateral column; and (*c*) the *fasciculus cuneatus* in the posterior column. These all consist of fibres that connect the white matter and the anterior and posterior roots with the grey matter at different levels and do not ascend directly to the brain.

Ascending Tracts.

Terminating Tracts.

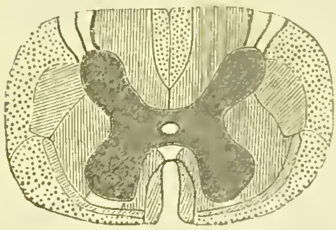


Fig. 152.—Section showing Columns of Cord.

Course of Motor Impulses.

The great mass of motor impulses originating in the cerebrum pass through the pores into the anterior pyramid in the medulla, and then cross over and descend in the cord by the crossed pyramidal tract. a smaller part remaining uncrossed and descending by the direct pyramidal tract.

The antero-lateral descending tract connects the spinal cord and medulla, and is the medium for reflex impulses from the latter centre.

In the ascending tracts, sensations of *pain* are conducted upwards by the ascending lateral tract; of *touch* by the column of Goll; that of *muscular sense* is uncrossed and ascends by the cerebellar tract and the column of Goll; of *temperature*, by the lateral tract; *reflex sensations* are probably conducted by various paths. As a rule, *motor fibres decussate* in *the medulla* before they enter the cord, and *sensory fibres in the cord as soon as they have entered* by the posterior roots. The motor fibres are closely connected with the large cells in the anterior cornu for the purpose of carrying out complicated co-ordinated movements.

Course of Sensory Impulses.

The *nutritive* or *trophic* centres of the descending motor

nerves are in the *brain*, hence they degenerate downwards when cut; and those of the anterior spinal nerves are in the *large polar cells* of the anterior column, hence these degenerate distally. On the other hand, the trophic centres of the ascending column lie probably in the *ganglion* on the posterior roots of the spinal nerves, there being no evidence that this ganglion has any reflex or automatic properties.

Trophic Centres.

3. THE REFLEX FUNCTIONS.

We must now consider the **reflex functions** of the cord. We have seen that for a reflex action *three* things are requisite: an afferent and efferent fibre and a nerve cell or centre. Reflex actions are essentially involuntary, though they may be often started, controlled, or directed by the will. They may be

Reflex Functions.

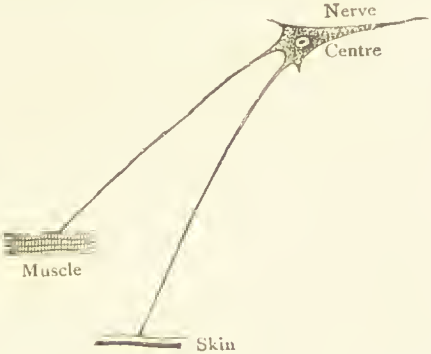


Fig. 153.—Diagram of Reflex Action.

natural or acquired. In health they have always some good end in view; in disease they may be injurious or useless, as the movements in chorea, etc.

In reflex action the nerves may belong (1) to the *cerebro-spinal*; or (2) to the *sympathetic* system; or (3) to *both*.

Reflex Nerves.

(1) In sneezing, coughing, swallowing, etc., both afferent and efferent nerves are cerebro-spinal, yet the action is purely involuntary.

(2) In secretion, digestion, etc., both afferent and efferent nerves are sympathetic.

(3) In blushing or secreting saliva the afferent nerve is cerebro-spinal, and the efferent sympathetic; in convulsions and many hysterical movements the afferent is sympathetic, and the efferent cerebro-spinal.

All these are *natural reflexes.* Of acquired reflexes we will speak when we consider the brain. Reflexes in the cord may be divided into three classes:—

Simple, when a single movement on one or both sides, according to the intensity of the stimulus, is produced.

Classes of Reflex Action.

Spasmodic, when the stimulation is sufficient to throw into spasmodic action large groups of muscle; and *Co-ordinate*, when a single sensation sets into action large groups of muscles for purposive action. Strychnine has a special power of so increasing the excitability of the reflex centres that the slightest stimulus produces the most violent spasms.

Character of Reflexes.

There is a difficulty of observing pure spinal reflexes in mammals owing to the amount of shock produced in removing the brain. But there is no doubt that they became *simpler* the *higher* we ascend in the scale.

In frogs the purposive character of these movements is well marked. If a drop of nitric acid be placed on the right flank of a frog deprived of its brain, and therefore unconscious, it will at once be wiped off with its right foot. If, however, the right foot be cut off, it will use its left.

Reflex Phenomena.

Reflexes are much more easily set up by stimulating the end organ (as the skin) than by irritating the afferent nerve itself. The contraction of a muscle does not vary with the amount of stimulus applied, but is constant.

The greater part of the time taken up in a reflex aet is occupied by the profound changes in the central cell by which centripetal is converted into centrifugal force, there being a great deal more involved than is implied by the word "reflexion."

Reflex often strongly resemble voluntary acts in all but their cause.

If the tail of a headless eel be gently touched it will be moved towards the side touched; if sharply, it turns away from it.

Reflexes can be *inhibited* by special mechanism for the purpose. They can be stopped by the will when it is active. For instance, when asleep if the palm be tickled the hand eloses; when awake it does not. An involuntary start can often be controlled. Sometimes the inhibitory power is limited. We can stop our respiration a certain time, but beyond that the reflex meehanism overpowers our will and we cannot die by holding our breath.

Inhibitory Reflexes.

Apart from the will there is believed to exist in the eorpora quadrigemina a *controlling centre* over the spinal reflexes. They certainly are more active when the brain is gone.

Controlling Centres.

Again, strong sensations may stop a reflex, as rubbing the nose prevents sneezing.

Poisons or chloroform inhibit reflexes, and so does a constant electric eurrent.

The value of certain spinal reflexes in the detection of spinal diseases is great. They are divided into three groups —*superficial*, *deep*, and *organic*. The first inelude all the skin reflexes in which certain involuntary movements are normally produced by the irritation of the skin in certain loealities, as tickling the soles of the feet, ete. In disease of the part of the eord where the eentre lies the reflex disappears.

Value of Reflexes.

The deep are tendon reflexes and are movements

obtained by striking a tendon, as in the knee joint. These may be diminished or augmented by disease.

The organic are reflexes ordinarily under the control of the will, as micturition, and which cease to be so in disease.

Centres in Cord.

There are also in the spinal cord **centres** for certain acts connected with the vital functions. There is a *dilating* centre for dilating the pupil of the eye: a *vaso-motor* centre for regulating the size of the smaller blood-vessels; a *sweating* centre. centres for *defæcation*, *micturition*, and for *reproduction*, and probably *trophic* centres. If the spinal cord be divided the animal can be kept alive, but if the part below the division be destroyed the animal dies from wasting, etc.

Section of Cord.

Complete section of the cord results in complete paralysis of motion and sensation of all parts supplied from below the lesion, though the muscles may retain their nutritive and electrical reaction. Ascending and descending degeneration then commences along the sensory and motor columns. Unilateral section results in paralysis on the same side and anæsthesia on the opposite side, with a narrow zone of anæsthesia on same side from those nerves which have not had time to decussate. There is also hyperæsthesia on the same side. the cause of which is not known.

CHAPTER XIX.

NERVE CENTRES: II.—THE BRAIN.

I. THE ANATOMY OF THE BRAIN.

The Three Membranes.

THE brain includes the cerebrum, or greater, and the cerebellum, or lesser brain. Both are enclosed in *three membranes*.

The Dura Mater.

The **dura mater** is the outer fibrous covering, and, unlike that of the cord, forms the *periosteum* of the skull bones, to which it is closely adherent. It is well supplied with nerves which, give it exquisite sensibility, but it is poorly supplied with blood-vessels. It is in two distinct layers which, separating in certain directions, form the venous sinuses. It forms three partitions in the skull; one, called the *falx cerebri*, is longitudinal and vertical, and separates the two hemispheres; another, similarly placed behind, the *falx cerebelli*, separates the two sides of the cerebellum; while a third, the *tentorium cerebelli*, is horizontally stretched between the cerebrum and cerebellum.

The subdural space (between this and the next membrane) contains lymph.

The Arachnoid.

The **arachnoid** membrane consists (if we count the endothelial layer lining the dura mater as part of it) of two layers, otherwise of one. Beneath the arachnoid is the *sub-arachnoid* space, filled with a network of loose connective tissue, by which it is united to the pia mater.

It contains *cerebro-spinal fluid*, which is a thin, saltish

fluid (Sp. Gr. 1010·, 99 per cent. water, and 1 per cent. solids, of which 9 are salts), analogous to lymph.

The Cerebro-spinal Fluid.

The average amount of it in the brain and spinal cord is *two ounces.* If the quantity be much increased, it produces coma ; if decreased, epileptiform convulsions. The cavities of the brain containing it are connected by the roof of the fourth ventricle with the sub-arachnoid space. It is believed to be partly the *lymphatic drainage* of the brain and partly formed by the cubical cells which line the ventricles (or brain-cavities), and which appear to have secreting functions.

The Pia Mater.

The **pia mater,** consisting of delicate connective tissue, not only closely surrounds the brain and dips into all the convolutions, carrying the blood-vessels everywhere with it, but at the transverse fissure forms the *velum interpositum* as it enters the ventricles, where, together with the numerous blood-vessels, it is called the *choroid plexus.*

The arachnoid and pia mater are much more closely united in the brain than spinal cord, the former, however, bridging over the convolutions into which the pia mater dips.

The Blood Supply.

The blood supply of the brain requires a few words. The total amount of the blood passing through the brain is not very great ; the value of the brain not consisting in the quantity but in the quality of its metabolism. There is probably a special vaso-motor centre in the brain for regulating its own blood supply. If this be impaired, the position of the head cannot be rapidly changed without the varying quantity of blood causing vertigo. *Mechanical means* are taken to mitigate the force of the heart's beat, and to ensure an equal distribution of the blood in the tortuous course of the carotid and cerebral actions, and in the free anastomoses of the *circle of Willis* at the base of the brain.

Perivascular spaces surround the arteries, so that they can

enlarge or decrease at the expense of the fluid around them.

In the arterial blood supply by the pia mater there is a very free anastomosis as the arteries break up into the capillary network by which the surface of the brain is supplied. The base, interior, and ganglia of the brain are all supplied from the circle of Willis, and here we get very few anastomoses. Each artery runs direct to its district and breaks up, but the capillaries do not unite with others.

The Arteries.

The large veins of the brain are not true veins, as they contain no muscle fibres and no valves, but are open canals, called sinuses, composed of the tough fibrous tissue of the dura mater, so that they can neither be compressed nor distended.

The Venous Muscles.

Though the brain cannot bear compression and is in a cavity with rigid walls, nevertheless, the quantity of blood it contains is not uniform, but varies invariably with the amount of cerebro-spinal fluid. The brain can thus become congested or anæmic like other parts.

The cerebro-spinal fluid is of special value at the base of the skull, where it forms a *water-bed* on which the medulla and other structures rest, thus preserving them from all jar.

The Water-bed.

The brain pulsates with the heart, the large arteries rhythmically moving its semi-fluid substance. It also rises during expiration and sinks during inspiration.

Turning now to a general examination of the brain itself, we find that it weighs from 43 to 50 ounces (in men 48, in women 43), falling in idiots in extreme cases as low as 16 ounces, and rising in some distinguished philosophers to 64 ounces. The weight of the brain is not, however, always a test of its quality.

Weight of Brain.

A washerwoman in France had a brain of 64 ounces.

White and Grey Matter.

It is composed of white and grey matter. The grey matter is arranged in *three ways* :—

(*a*) The *continuation of the central grey matter* of the cord

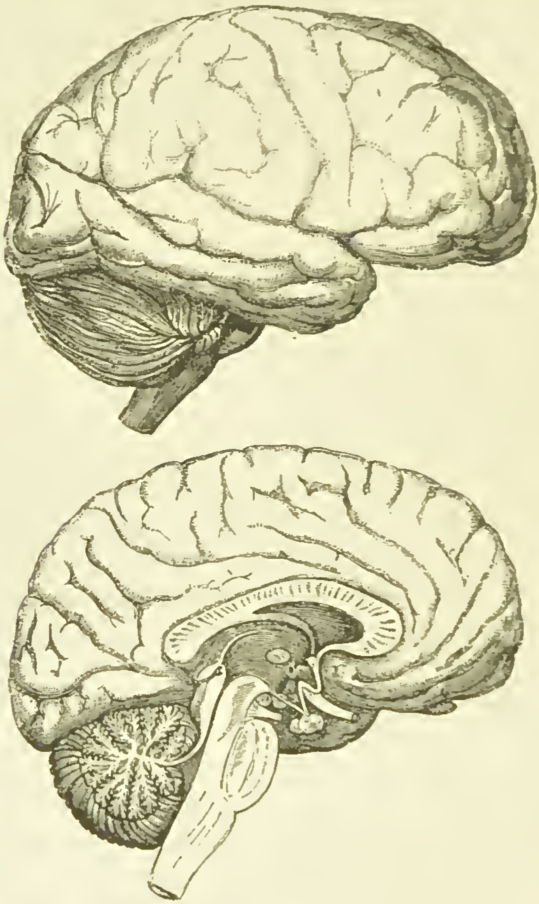


Fig. 154.—External and Sectional view of Brain.

for a certain distance. Here, between the end of the third to the end of the fourth ventricle arise most of the roots of the cranial nerves. Then there are (*b*) *scattered masses* of grey matter

Arrangement of Grey Matter.

imbedded in the central region. These include the corpus striatum, optic thalamus, locus rubra and niger in the crus,

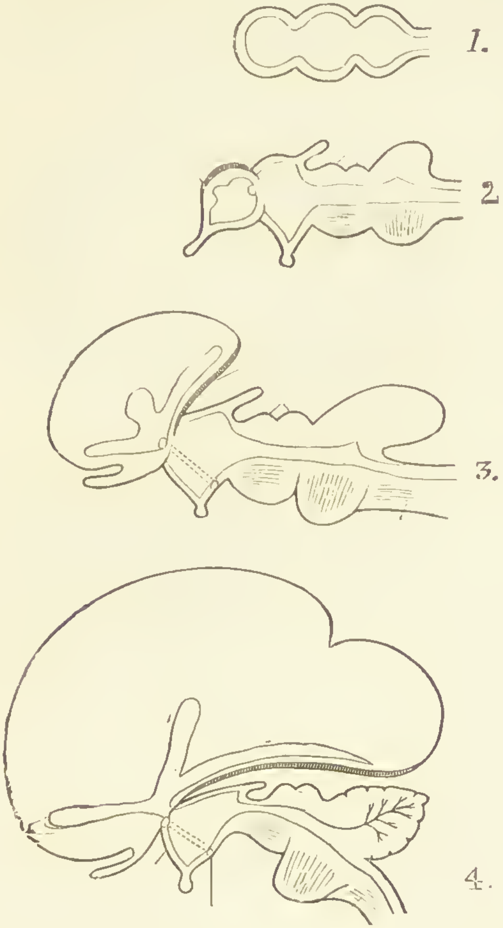


Fig. 155.—Diagram Illustrating the Progressive Changes in the Development of the Brain. (Yeo.)

1, Three vesicles in early embryo; 2, growth of lateral ventricle and corpora quadrigemina; 3, growth of hemispheres; 4, development of hemispheres.

the grey matter of the pons of the corpora quadrigemina and geniculata, and the corpus dentatum of the cerebellum.

And finally (*c*) the *whole surface in the cortex* of the brain is covered with a layer of grey matter about a third of an inch thick, and differing from all other grey matter.

Development.

In the embryo the upper part of the medullary tube presents a series of *three* outgrowths or vesicles, which form respectively the *hind*, *mid*, and *fore* brain.

Hind Brain.

In the **hind** brain the floor is formed by the medulla; the roof by the cerebellum (Fig. 156) and the pons Varolii; and the cavity is the fourth ventricle. The *pons Varolii* consists of transverse and longitudinal fibres; the longitudinal emerge at the front and form the *crura cerebri.*

Mid Brain.

These form the floor of the **mid** brain; in the roof are the *corpora quadrigemina*, the cavity being the *aqueduct of Sylvius*, or the *iter*.

Fore Brain.

In the **fore** brain the crura diverge, leaving a space, the *anterior vesicle* (the *third ventricle*), the floor being the *infundibulum*, and the roof the pineal gland. They enter masses of grey matter on each side of the optic thalami. In front of the third ventricle the crura spread out into two hollow masses above, which form the two *hemispheres*, with their cavities (the lateral ventricles) separated by a deep fissure and only united by the isthmus of the *corpus callosum*, which extends along one-third of their length. Beneath are two other prolongations forming the olfactory lobes. In the floor of each lateral ventricle is the mass called the *corpus striatum.*

General Structures.

The **general arrangements** of parts are therefore as follows:—When the spinal cord reaches the brain it widens and flattens, and at the same time the posterior septum opens out right down into the central canal, so as to lay the interior open after the manner of a split herring. Across the front of the medulla is a large, broad band of fibres like a bridge (hence called the *pons Varolii*), which connects the two parts of the

cerebellum, which is the size of a small apple, and rests on the medulla above. Beyond the pons the longitudinal fibres which pass through it diverge, as we have seen, so as to form two rounded pillars called the *peduncles*

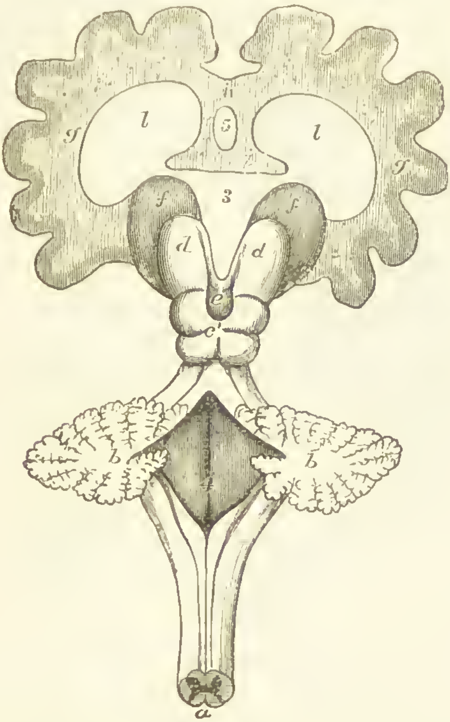


Fig. 156.—Diagram of Brain and Medulla Oblongata. (Yeo.)
a, cord; *b*, cerebellum; *c*, corpora quadrigemina; *d*, optic thalami; *e*, pineal gland; *f*, corpora striata; *g*, hemispheres; *h*, corpus callosum; *l*, lateral ventricles; 3, third ventricle; 4, fourth ventricle.

of the brain or crura cerebri. These pillars terminate on each side in two large masses of grey matter, the anterior one being the corpus striatum, the posterior the optic thalamus.

Some fibres of the crus pass, however, forwards directly through the *internal capsule* (a band of white fibres). From

these two masses the white fibres radiate like a fan, forming the two *cerebral hemispheres* (each being the size of a large fist, and forming the greater part of the cerebrum), terminating finally in the outer layer of grey matter that forms the convolutions of the cortex.

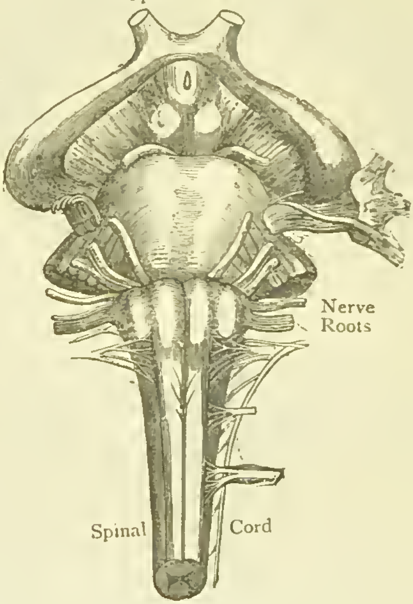


Fig. 157.—General View of Medulla

We will proceed to consider the structure of these different parts in further detail.

Structure of Medulla.

The **medulla** is pyramidal, with its broad end uppermost, and is about $1\frac{1}{4}$ inch long, 1 inch broad, and $\frac{3}{4}$ inch thick. It is a continuation of the spinal cord with important modifications. It has an anterior fissure, which extends as far as the pons, and the posterior fissure opens out into the central canal which forms the fourth ventricle of the brain, on the floor

of which grey matter is exposed. Each half of the medulla consists of *four structures*, from before and backwards—the *anterior pyramids*, the *olivary body*, the *restiform body*, and the *posterior pyramid.*

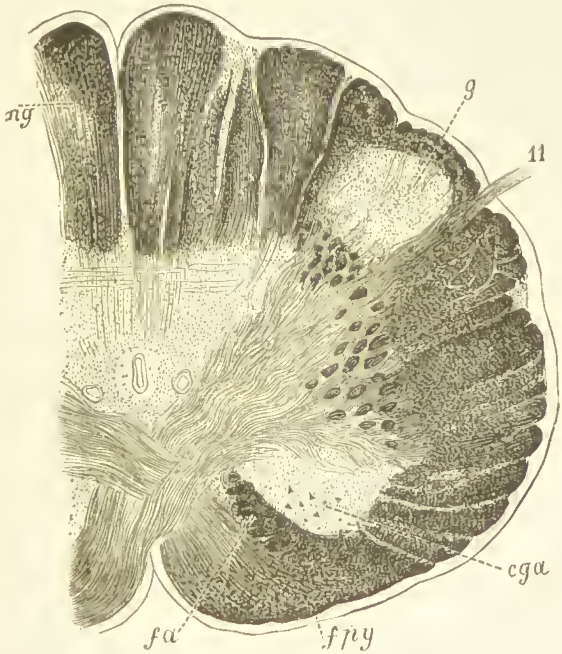


Fig. 158.—Transverse Section through the Medulla Oblongata in the Region of the Pyramidal Decussation.

fpy, Anterior pyramidal tract; *cga*, lateral nucleus of grey matter; *fa*, part of anterior column not decussating; *ng*, nucleus gracilis; *g*, gelatinous nucleus of posterior horn; 11, spinal accessory nerve. (Henle.)

The three **columns** of the cord are continued in the medulla as follows:—

Course of Spinal Column.

The direct pyramidal tract or *anterior column* becomes the anterior pyramid, the rest of the fibres of the column passing behind it.

In the *posterior column*, the column of Goll, or the posterior median column, becomes the posterior pyramid,

while the posterior external column or *fasciculus cuneatum* becomes the restiform body.

In the *lateral column* the cerebellar tract goes with the restiform body to the cerebellum; the crossed pyramidal tract decussates and goes to the anterior pyramid of the opposite side, while the lateral tracts ascending and descending are continued on to the cerebrum.

The **olivary bodies** are two well-marked oval bodies lying behind the anterior pyramids.

The grey matter of the medulla consists of that of the

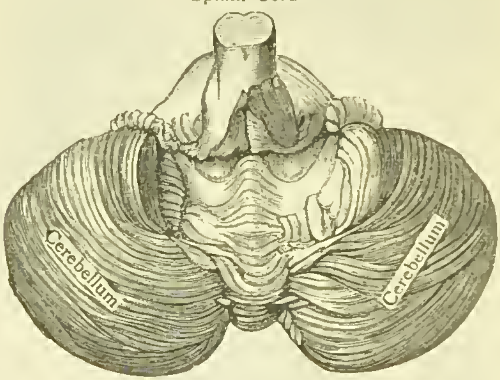


Fig. 159.—Under-surface of Cerebellum, showing vermiform process.

cord with additions, rearranged, however, in various masses in the floor of the fourth ventricle.

The **cerebellum** is about 4 by $2\frac{1}{2}$ by 2 inches, and consists of a body and three pairs of crura. The body is divided into right and left hemispheres united by a central portion, the *vermiform* process. The surface is not in convolutions like the cerebrum, but in fine, vertical lamina, or plates. The surface is grey matter with the white inside, arranged in a branched manner like a tree. In the middle of the white matter is a grey mass called the *corpus dentatum*.

Cerebellum.

There are three pairs of crura in the cerebellum :—

The *upper crura* run to the cerebrum and form the sides of the fourth ventricle ; the *middle crura* form the pons Varolii ; while the *inferior* run to the medulla and form the restiform bodies.

Pons Varolii.

The **pons Varolii** consists, as we have seen, of transverse cerebellar fibre externally, and longitudinal medullary fibre internally ; with also some grey matter continued on from the medulla.

The Crura.

Each **crus cerebri** which emerges from the fore part of the medulla beneath the pons consists of two parts :—the *tegmentum* or posterior part, and the *crusta* or anterior part. Between the two is a mass of grey matter called the *locus niger*.

Course of Nerve Fibres.

It will be convenient here to take a general survey of the direction of the nerve fibres in the brain, and particularly those in the crus.

The course of the nerves is more difficult to trace in the brain than in the spinal cord. Besides commissural and intercellular fibres of all sorts, Meynert divides all nerves into three great divisions :—

Meynert's Divisions.

1. Those that pass to and fro between every part of the cortex and the great basal ganglia of grey matter (the corpora striata, optic thalami, corpora quadrigemina, etc.) which convey sensory perceptions to the mind, and convey motor impulses from it.

2. Those fibres that extend from the basal ganglia through the crura to every part of the spinal cord ; and

3. The peripheral fibres that issue from the cerebrospinal system and form what we call the nerves proper.

Motor and Sensory Tracts.

The crura cerebri are divided into *motor* and *sensory* tracts. The lower, or inferior, or *pedal* part of each crus (called also the crusta) is the *motor* tract, and is connected with the anterior pyramids in the medulla.

The upper, or superior part, or *tegmentum*, consists of *three* sets of fibres. The *outer third* connects the cerebellum with the occipital and temporal lobes of the brain; the *inner third*, the cerebellum with the frontal lobes; while the *middle third* carries the sensory fibres, and is connected with the olivary bodies in the medulla and the lateral and posterior columns in the cord.

The Corpora Quadrigemina.

Above the crura, forming the roof of the aqueduct of Sylvius, that connects the third ventricle in front with the fourth behind, are the **corpora quadrigemina** (the optic lobes of the lower animals). These are four masses of white and grey matter, the size of peas, arranged in two pairs, anterior and posterior; the anterior pair is connected with the *optic tract*.

The Basal Ganglia.

The **basal ganglia** consist mainly of four large bodies, the *corpora striata* in front, and the *optic thalami* behind.

The **corpus striatum** is a striated mass of grey and white matter imbedded in the white substance of the hemispheres.

The **thalamus opticus** is mainly grey matter, the two being connected by a soft band in the third ventricle.

The Hemispheres.

The **cerebral hemispheres** cover all the rest of the brain, including the cerebellum, and consist of two halves divided by the *great longitudinal fissure* which passes right through to the base, being only interrupted by a band of white fibres (corpus callosum) that connect the hemispheres together along their middle third. The surface or cortex is grey, the interior is white. The area of the surface is greatly increased by convolutions with depressions or *sulci* between, which cover the whole surface of the hemispheres.

These are divided into five lobes by depressions deeper than the rest. The *frontal* lobe is in front, separated from the *parietal*, or middle lobe, by the *fissure of Rolando*. The

temporal lobe at the side is separated from the frontal by the *fissure of Sylvius.* The *occipital* lobe behind is separated from the parietal by the *parieto-*

Five Lobes.

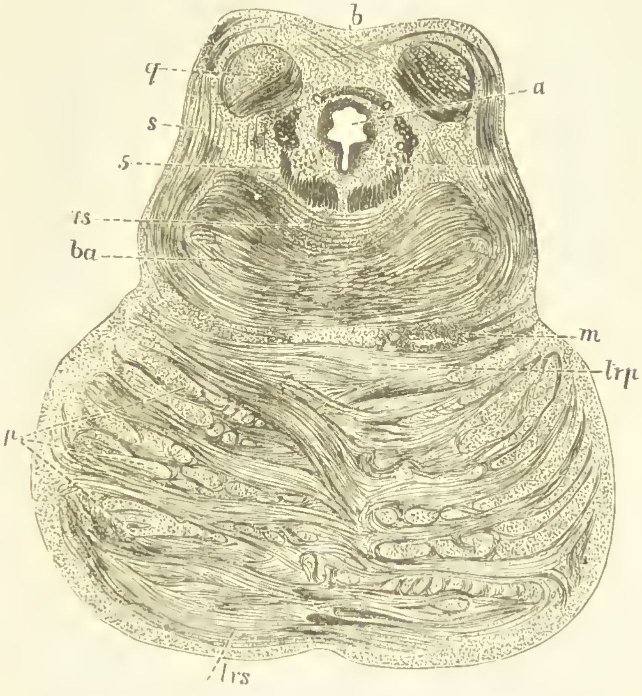


Fig. 160.—Transverse Section through the Lower Corpus Quadrigeminum and the Pons Varolii.

a, Aqueductus Sylvii; *b*, crossing of the brachia of the lower corp. quadrig.; *q*, ganglion of the lower corp. quadrig.; *s*, pedunculus of the lower corp. quadrig.; *ba*, tegmentum; 5, the descending root of the fifth; *p*, bundles of the anterior pyramidal tracts in cross-section; *trp*, deep transverse bundles of the pons; *trs*, superficial transverse bundles of the pons. (Meynert, in Stricker's Manual.)

occipital fissure. The *central* or internal lobe is called the *island of Rheil.*

The white matter consists of fan-like fibres connecting every part of the cortex with the two basal ganglia, and of innumerable commissural fibres. The grey matter consists of several alternate

Structure of Hemispheres.

layers of darker and lighter shades, according to the arrangement of the cells that compose them.

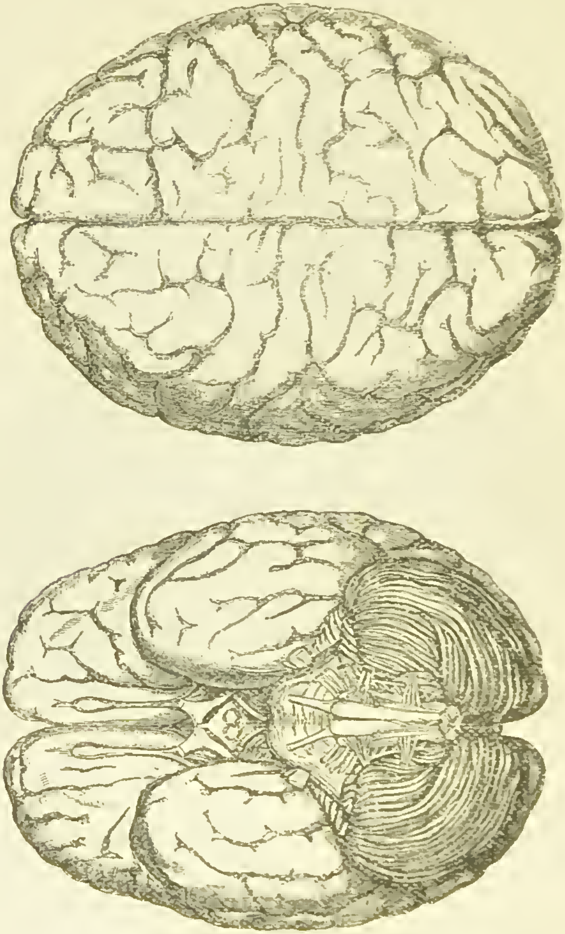


Fig. 161.—Surface and Base of Brain.

There are five layers that resemble generally the three in the cerebellum. The *outer layer* is principally neuroglia with small branching cells; the *next* consists of a close

Fig. 162.—Vertical Section through the Grey Matter of a Cerebral Convolution.

a, Superficial layer; *b*, closely-packed small ganglion cells; *c*, the layer of the cornu Ammonis, this being the principal layer; *d*, the "granular formation," small multipolar ganglion cells; *e*, the layer of spindle-shaped ganglion cells. (Meynert, in Stricker's Manual.)

Fig. 163.—Another Section of same.

layer of small pyramidal ganglia cells. These two may be compared to the molecular layer of the cerebellum. The *third* layer resembles Purkinje's cells, and consists of many large pyramidal ganglia cells, each having a process running to the surface, and inner processes which are branched, and one unbranched inner process that becomes a nerve. The *two inner* layers consist of small ganglia cells resembling the layers of the cerebellum.

Layers of the Cortex.

These cells differ in character, as in the cord, according

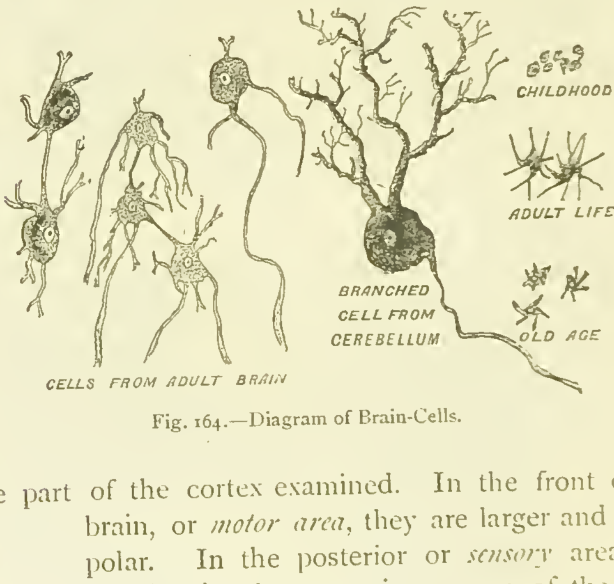


Fig. 164.—Diagram of Brain-Cells.

to the part of the cortex examined. In the front of the brain, or *motor area*, they are larger and multipolar. In the posterior or *sensory* area they are (as in the posterior nerves of the cord) much smaller.

Cells in Cortex.

Many cells are pyramidal. In these *one* process ascends from the apex to the cortex. *Another* process proceeds from the second angle as a nerve fibre into the white substance, where it becomes medullated, while a *third* continues to subdivide till it is lost in a network of fibres. These cells are contained in lymph spaces. The substance

of the grey matter is made up of cells, neuroglia, and the branching connective-tissue fibrils of the pia mater. The grey matter is five times as vascular as the white.

The **ventricles** of the brain are *five* in number; the *two lateral* ventricles in the hemispheres each having three cornua, ascending, descending, and posterior. In the floor rises the corpus striatum, and behind, the optic thalamus.

Ventricles of the Brain.

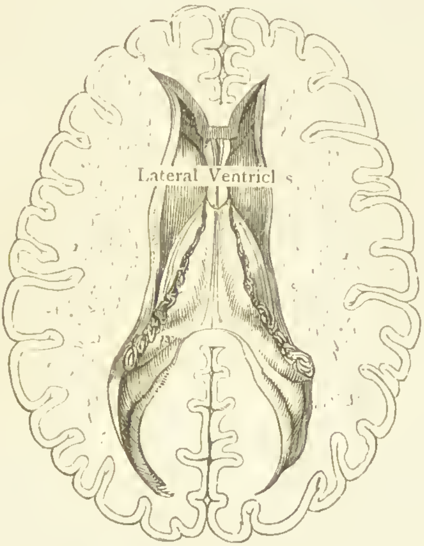


Fig. 165.—Lateral Ventricles of Brain.

The sides of the *third ventricle* are formed by the optic thalami, the floor by the infundibulum, the roof by the velum interpositum (a fold of pia mater) and the pineal gland. It communicates in front by the *foramen of Monro* (a Y-shaped passage) with the lateral ventricles, and behind by the aqueduct of Sylvius with the *fourth ventricle* in the medulla.

The *fifth ventricle* is a small cavity in a delicate double

partition or *septum lucidum*, between the two lateral ventricles. All these cavities communicate with the subarachnoid spaces and the central spinal canal.

The lowest vertebrata (amphibia) have no specialised brain. As we ascend in the scale the optic lobes are first highly developed, the cerebellum being a small band, as in reptiles and birds. In mammals the optic lobes decrease in size, while the hemispheres increase, together with the cerebellum, which gets more and more overlapped by the cerebrum as we ascend.

The convolutions increase in complexity and number with the mental development of the animal, being less in a child than in a man. Increase of convolutions means, of course, increase of grey matter.

2. THE FUNCTIONS OF THE BRAIN.

Turning now to consider the functions of the brain, we may with convenience roughly divide the brain into four parts, of which one is the cerebellum; the rest —the *upper* region of the cerebrum or cortex: the *lower*, or medulla; and the *middle*, including all between.

Four Divisions.

The **upper** may be said generally to be the seat of intellectual life, or of the *spirit;* the **lower** of the necessary vital functions that carry on and store life forces—the vegetative side of our life or *body;* while the **middle** region is that of the functions of animal life or the *soul.* All action of the upper region is the result of the direct action of the mind; that of the lower is purely reflex or involuntary; that of the middle region is partly acquired reflex (or action once voluntary, but which by habit becomes reflex), and partly voluntary, under the control of the upper region.

Spirit, Soul, and Body.

In conversing while walking, the whole of these four regions are in activity. The cerebellum maintains the equilibrium and the erect position; the medulla the passive life of the body in the beating of the

heart, the respiration, etc.; the middle region displays the animal life or soul in the movements of the legs and muscles of speech ; while the mind or spirit directs in the higher region the whole and gives intelligence and meaning to the words uttered. On the other hand, the phenomena of drunkenness show the successive paralysis of spirit, soul, and body. The upper region is affected first, and noisy manifestations of animal life are displayed unruled by the spirit. If more be drunk, the middle region and the cerebellum are paralysed, and if the man is dead-drunk the medulla alone remains active, carrying on the functions of passive physical life. Equilibrium is lost and all expression of the animal life and energies. If more of the poison be now administered, the action of the medulla is finally arrested and the man no longer dead-drunk, but dead.

We will consider the four regions of the brain in detail.

Structure of Cerebellum.

The grey matter of the cerebellum is arranged in three layers : a molecular layer externally, consisting of fine fibrils, neuroglia and branches of nerve cells below. Then comes a layer of very large cells (**Purkinje's**). These cells send one process inwards, while outwardly they branch in a perfect network of fibres. The third layer is called the nuclear layer, which consists of large numbers of small nerve cells that branch in the layers, with one process running outward into the nuclear layer and dividing at right angles near the surface. From the fact that the single nerve process of Purkinje's cells passes downwards and inwards while it branches outwardly, and that the nerve processes in the nuclear layer pass upwards and outwards while they branch inwardly, it is supposed that the *former* may be *efferent* or motor, and the latter *afferent* or sensory ; there is, however, no proof of this. Each Purkinje's cell lies in a lymph space.

Purkinje's Cells.

Functions of Cerebellum.

The cerebellum generally has to do with co-ordination of muscle and the preservation of equilibrium. When it is injured these powers are wanting, but neither will-power nor consciousness are affected ; but after its removal they are often recovered after a

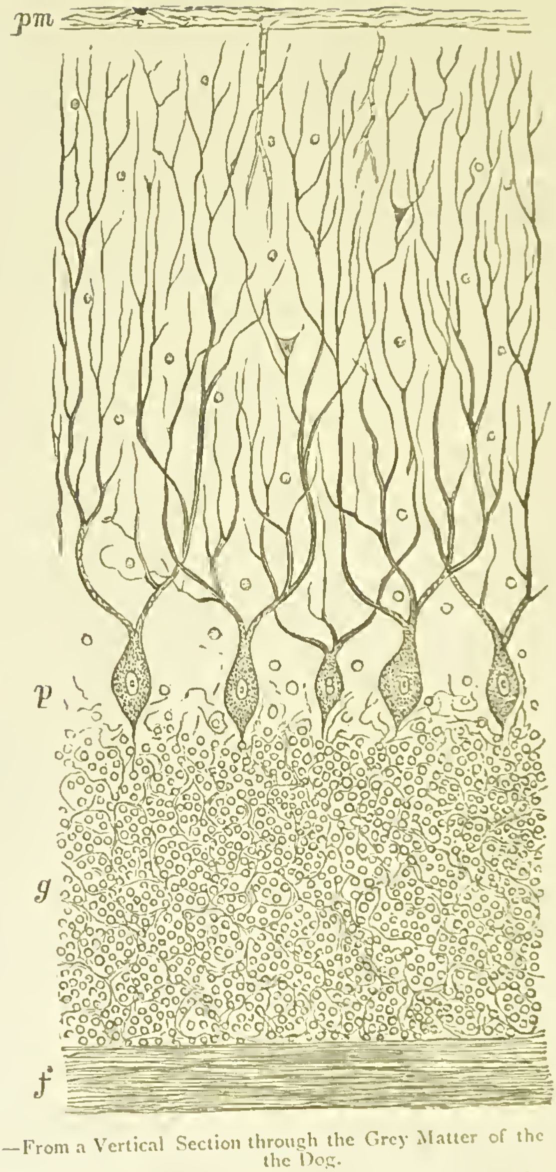


Fig. 166.—From a Vertical Section through the Grey Matter of the Cerebellum of the Dog.

pm, Pia mater ; *p*, the ganglion cells of Purkinje ; *g*, the nuclear layer ; *f*, the layer of nerve fibres (white matter).

time. On removing the cerebellum in a pigeon it could neither stand nor fly, though its will and intelligence were intact.

In man injury to the cerebellum produces staggering and reeling. In cerebellar disease you may get three classes of "forced" movements, *circus* or round as in a ring, *top* or circling as on a pivot, and *rolling* on long axis of body. All three occur in a dog in an epileptic fit. This part of the brain has no connection with the reproductive organs.

Dividing the cerebrum into three regions according to their general functions, we will consider the lowest or medulla first. Like the cord the **medulla** conducts and reflects impulses. It has also a few controlling, and possibly some automatic centres.

The Lower Region.

Like all other parts of the brain it depends for its activity on a free supply of healthy material blood.

Functions of the Medulla.

The principal reflex centres of the medulla are as follows:—

Closure of the eyelids, sneezing, coughing, mastication, deglutition, sucking, vomiting, secreting saliva, dilating the pupil, respiration, cardio-inhibitory, cardio-accelerating, vaso-motor centre, vaso-dilating centre, spasm centre, and sweat centre. Similar centres to some of these exist in the cord, but they are always subordinate to the corresponding centres in the medulla.

Reflex Centres.

Closure of the eyelids. The fifth is the afferent, and the seventh the efferent nerve in this case. Both eyes are closed in reflex action.

Shutting the Eyes.

Sneezing. The afferent nerve is the nasal branch of the fifth, and this reflex action, which is quite involuntary, may be inhibited by compressing the nasal nerve in the nose.

Sneezing.

Coughing, Mastication, Swallowing.

Coughing. The tenth is the afferent nerve: the centre is just above that of respiration.

Mastication. This centre is affected in lock-jaw.

Swallowing. The action of this centre seems to interfere with the cardio-inhibitory centre, so that in sipping water the heart beats more quickly. This centre is affected in hydrophobia.

Respiratory. This centre is said to be partly automatic, because it is excited by the quality of blood circulating in it, as well as by nerve impulses. It is double on each side, one part presumably for inspiration, and the other for expiration. Respiration may be altered by the will, but it cannot be checked indefinitely. The tenth is the afferent nerve. If divided on one side, respiration on that side is slowed. If the central cut-end be stimulated, breathing is arrested on the one side only. After section of both afferent nerves the centre retains its activity, being stimulated by the blood. In *apnœa* the blood is saturated with oxygen, and even fails to stimulate the centre as in fœtal life. In *eupnœa* the respiration and blood are normal. In *dyspnœa* the oxygen is decreased and the CO_2 increased, and the breathing is laboured. *Asphyxia* is caused by the circulation of venous blood in the medulla, or from excessive febrile heat, which exhausts the centre. The centre can be influenced by the will to a certain extent, also reflexed by cutaneous nerves, as in a cold bath. Other nerves can slow it. The mechanism of inspiration and expiration appears to be automatic, the two centres acting alternately. The dilatation of the lungs stimulates the expiratory centre, and the contraction of the lungs the inspiratory centre in turn.

Heart Inhibitory Centre.

Cardio-inhibitory centre. This acts by the tenth nerve and can be excited reflexly through several abdominal nerves, or through the other

vagia. It is partly inhibited by swallowing. Digitalis and other drugs stimulate it.

Cardio-accelerating. The course of the nerve fibres is believed to be through the sympathetic.

Heart Accelerating Centre.

Vaso-motor centre. The centre near the olivary bodies supplies all muscles of the blood-vessels with nerves. Stimulation causes contraction of the vessels, paralysis causes dilatation. Chloral and curari stimulate the centre and continue to act until the centre is cut away.

Vaso-motor Centre.

It is excited directly by the condition of the blood, by psychical influences, by poisons, and by electricity. It is excited reflexly by pressor fibres that run from various parts of the skin, etc., and inhibited by depressor fibres, which are specially numerous in the superior cardiac branch of the tenth (called the depressor nerve).

This centre necessarily affects the temperature of the body, in part, and as a whole. If a vaso-motor nerve be divided, the part supplied gets full of blood and hot. If the cut end be irritated, the vessels contract and it gets cold. If a large number of nerve-controlling skin capillaries are paralysed, the general temperature falls, though the part affected gets warmer. Indirectly it also affects the activity of the heart. It also contracts subordinate centres in the cord.

A **vaso-dilator centre** is believed to exist, though its existence is not quite proved. Its action is the reverse of the vaso-motor centre.

Spasm centre. This is near the pons, and, if excited directly by venous blood or poison, it produces general spasms. The **sweat centre** is double; one may thus produce unilateral perspiration. It is affected by many nerve poisons.

Spasm and Sweat Centres.

It will be convenient to consider the **upper** and **middle**

T 2

regions together, as, although the actual centres for the various functions of animal life are beneath the cortex, they are, at any rate as long as they are voluntary, set in motion from definite areas in the cortex acted on by the will, mind, or spirit of man.

Upper and Middle Region.

That the hemispheres, and particularly the cortex, are the centres for intelligent brain action, is proved by direct experiment. A frog deprived of its hemispheres can live and act if stimulated, but has no voluntary movement, though it can execute almost any which it cannot do with the cord alone. Placed on its back it will return to its natural position. It swims perfectly, and will rest on a bit of wood. It will croak if stroked. Volition alone is absent. The body has lost its animating spirit and is a mere complicated machine. This psychical activity resides in *both* hemispheres, and if one be destroyed may be taken up by the other. It is impossible to say from this that the cortex *is* the mind. It is more reasonable to believe that it bears the same relation to the mind that the musician does to the instrument; neither can express itself without the appropriate instrument: which, in one case is the organ or piano, in the other the cortex. The cortex is thus the organ of the mind, but it forms no necessary part of the machinery of the body. Birds can fly perfectly when it is removed. Practically the higher we go in the scale of animals the more difficult it is to distinguish between the presence or absence of will-power in the acts that are done. The functions of the cortex can be abolished by injury or pressure which produces unconsciousness. Unilateral destruction of the cortex has taken place in man without loss of mind or will-power.

Intellectual Functions of Cortex.

The Brain and the Mind.

The degree of intelligence depends on the size of the cerebral hemisphere, and the number and depth of the convolutions.

The spontaneous activity of the cortex is the most remarkable feature of life. To account for it by discharge of nerve energy is unsatisfactory, for we have no evidence that any such metabolism is carried out in connection with any other nutritive influence. The activity of the cortex is no doubt largely due to afferent impulses. If these are wholly withdrawn and nutrition of brain continued, all voluntary movements and probably consciousness would go. A patient with general anæsthesia, deaf in both ears and blind in one eye, went to sleep whenever the remaining eye was closed; nevertheless, though the prompting of the act may be an afferent impulse, the carrying of it out or its inhibition is purely voluntary.

Course of Cortex Action.

Certain physiologists deny free-will or spontaneous action altogether, and assert that all brain action is essentially reflex, and that if we knew all about a man we could predict certainly what he would do at all times.

All voluntary acts belong to the cortex alone. All psychical processes take up a certain portion of time; the perception of touch takes about one-seventh of a second, of hearing one-sixth of a second, of sight one-fifth of a second, of taste one-seventh of a second.

Time for Different Impressions.

During sleep a person may be compared to an animal with its hemispheres removed. Sleep is caused partly by the using up of the stock of potential energy in the brain nerve cells, which require to be re-charged, and partly by the suggestion of position and surroundings adopted at the time.

Cause of Sleep.

Besides the general fact that the anterior part of the brain is for volition and the posterior for perception, in 1870 it was discovered that the stimulation of certain regions of the cortex produced definite co-ordinated movements on the opposite side. If slightly stimulated, the movement alone was produced; if strongly, convulsions occurred. The same results occurred if the

Motor Areas.

white matter beneath were irritated, but the latent period was longer.

All the anterior part of the brain is concerned in movements of various sorts, excepting part of the frontal lobes, which is believed to be the seat of the ideal and thought centres that do not produce bodily activity. The differentiation of certain cortical areas that produce certain movements

Seat of Ideal Centre.

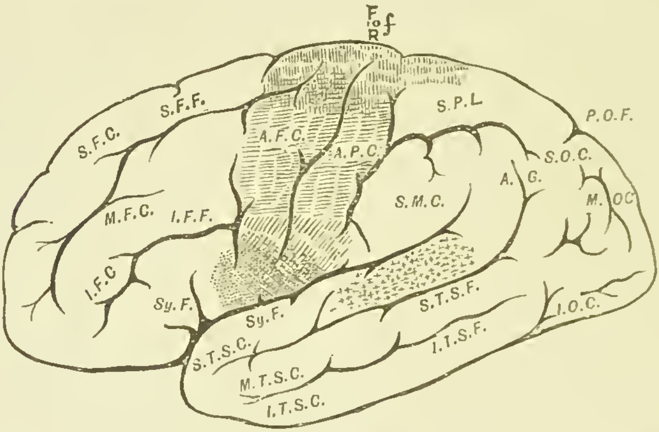


Fig. 167.—Side View of Convolutions of the Brain.

S, M, and I F C, Superior, middle, and inferior frontal convolutions: Sy F, Sylvian fissure; S F F, I F F, superior and inferior frontal fissures; F of R, fissure of Rolando: A F C, ascending frontal convolution; A P C, ascending parietal convolution; S P L, superior parietal lobule: S M C, superior marginal convolution; A G, angular gyrus; P O F, parieto-occipital lobe; S, M, and I O C, superior, middle, and inferior occipital convolutions: S, M, and I T S C, superior, middle, and inferior temporo-sphenoidal convolutions; S and I T S F, superior and inferior temporo sphenoidal fissures.

increases as we ascend from the frog to the monkey. The size of the area corresponds to the importance of the part. That for the arm is enormous as compared with that for the trunk, and that for the thumb is enormous in proportion to that for the arm. It may be observed that the pyramidal tracts, the channel of these movements, increase from the dog to man.

Motion takes place on touching the cortex, because the part is connected histologically by nerve threads with the motor centres beneath, but in what way the stimulus of the mind

or will is applied we know not. In briefly considering the results obtained by electrical stimulation, we must bear in mind the coarseness of the method, which is something like trying to play the piano by striking it with a long pole.

Stimulation of Cortex.

The following are the principal areas mapped out at present on the monkey's brain, and also transferred to the same districts in the human brain.

Fig. 168.—Diagram of Motor Areas.
T, Trunk. L, Leg. A, Arm. H, Head. F, Face.

Experiments show that the areas in man are similar to, though not identical with, those in the monkey. So accurately have these been mapped out that they have been turned to practical uses in localising tumours which have been thus removed. The removal of any area in the monkey produces complete motor paralysis in the region on the opposite side of the body supplied by it, and, in man, destructive disease has the same results.

The lower we descend in the scale, and the less movements are directly controlled by will, the less does a lesion or removal of the cortex affect them. Again, the artificially acquired reflex habits, such as playing the violin, are more permanently affected by injury to the cortex than naturally acquired reflexes, such as associated movements of the eyes and head, etc.

Effect of Injury to Cortex.

With regard to sensation, the areas are not so definitely

localised, for obvious reasons, as in motion, it being far more difficult to ascertain when an animal experiences a sensation than when it moves. There is no doubt, however, that they exist mainly in the occipital and temporal lobes. The result of destruction of these districts appears to be that the *mechanism* of sensation is *left;* a dog will see, hear, and feel, but the *consciousness* is *lost*, it does not know what it sees, hears, or feels, being unconscious.

Sensory Areas.

The *centre for speech* is in the *third left frontal* convolution. Here lie on both sides the centres for the movements of lip, tongue, face, etc., but the psychical power of speech only appears to be in the **left**-side, except in left-handed people, who are therefore right-brained, that is, the superior powers of the left brain (including speech) are in them transferred to the right hemisphere. In deaf mutes this convolution is very small, in idiots and monkeys only rudimentary. The speech tract passes through the crusta in the left crus into the left half of the pons, and there crosses and enters the floor of the fourth ventricle, where all the nerve centres concerned in speech are found.

Centre for Intelligent Speech.

The loss of the power of speech is called *aphasia*, and may consist of the loss of power to articulate the words, or to remember them, or to connect the right word with the right thought.

Loss of Speech.

The *centre for sight* is in the occipital lobes. and long-continued blindness is followed by atrophy in these parts.

Centre for Conscious Sight.

It may here be remarked that whereas originally the whole of the brain was under the direct control of the will, excepting the lower natural reflex districts. habits long continued tend to form through life an ever-increasing series of artificial or acquired reflexes, or co-ordinate movements independent of

Artificial Reflexes.

direct will-power, though they can be inhibited at will by it, thereby differing from most natural reflexes. It is thus that practice gives ease, and early apprenticeship to a trade is so valuable. Such acts as swinging the leg and arm of opposite sides together when walking, that of walking itself, of reading, of playing musical instruments, etc., are instances of acquired reflexes. The theory of the establishment of these actions appears to be that whereas at first they originated in the cortex, or at any rate the afferent impulse arrived there and the ensuing efferent impulses were directed by the will, after a time constant repetition of the same series of acts, following certain impulses, formed paths, and probably nerve fibres, between the cells involved ; and the impulse arriving, no longer required to go to the cortex (as it were for orders), but at once traversed the well-worn channels that produced the act.

How Formed.

With regard to the *region of thought* and all intellectual processes, there appears little doubt that these are connected with the anterior part of the frontal lobes, which in idiots are found deficient, in intelligent men greatly developed.

Region of Thought.

With regard to the corpus striatum and the optic thalamus, the original idea that the former was motor and the latter sensory centres has now to be considerably modified. All we can say with certainty is that electrical stimulus of the former is followed by contraction of the opposite half of the body, whereas no such effects follow stimulus of the latter. The cause of the contraction, however, is believed to be chiefly due to pressure on the internal capsule.

Functions of the Basal Ganglia.

The **internal capsule** is a narrow band of fibres from the motor area, that lies at first between two parts of the corpus striatum, the caudate and ventricular nuclei, and afterwards between the corpus striatum and optic thalamus. Though it

The Internal Capsule.

contains principally motor fibres, some sensory fibres run in its posterior part.

It has recently been suggested by Gowers that the corpora striata have functions analogous to and subordinate to those of the cortex. Lesions of the corpus striatum and optic thalamus do not produce loss of motion or sensation, provided the internal capsule be not pressed. It is possible that the optic thalamus may be a centre for acquired reflex acts.

Injury to one crus causes paralysis of the opposite side. Destruction of the corpora quadrigemina on one side causes loss of sight in the opposite eye; total destruction causes total blindness as well as loss of equilibrium and co-ordination.

Pineal Eye.

The **pineal gland** that lies in front has lately been shown to be a probable centre for sight connected in some lizards with a disused central eye lying in the middle of the skull, about the position of the anterior fontanelle.

3. THE CRANIAL NERVES.

Cranial Nerves.

Of the *twelve pairs* of cranial nerves, the 1st, 2nd, 8th, 9th, and part of the 5th, are special-sense nerves: the principal part of the 5th is a nerve of common sensation; while the rest of the 5th, with the 3rd, 4th, 6th, 7th, and 12th, are mixed. The 9th, 10th, and 11th are both motor and sensory or mixed nerves.

The Olfactory Nerves.

The **first cranial** or olfactory nerves consist of a pair of bulbs of grey matter at the anterior part of the base of the brain. These bulbs are connected together and partly decussate behind, arising in front from the opposite temporo-sphenoidal lobe. From twelve to fifteen nerve filaments pass down through the cribriform plate of the ethmoid plate from each bulb into the nose, where they enter the mucous membrane. These are the only nerves of smell.

The **second cranial** or *optic nerves* arise from the anterior corpora quadrigemina and the optic thalamus. From here a broad band of fibres passes up to the psychical visual centre in the cortex at the apex of the occipital lobe on the same side.

The Optic Nerves.

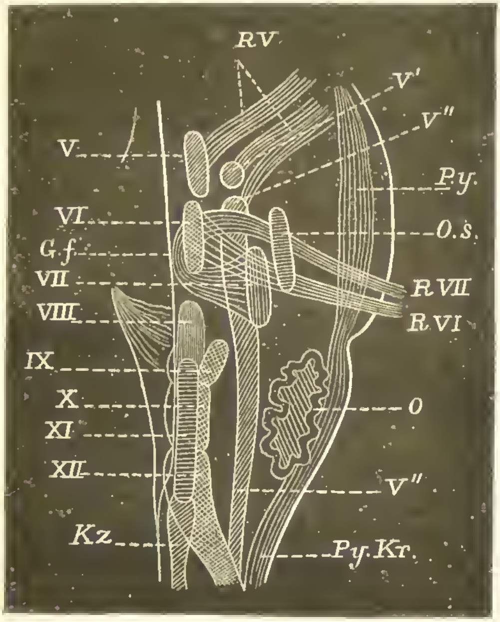


Fig. 169.—Lateral View of Medulla, showing the position of the principal nuclei. (*After Erb.*)

Py., Pyramidal tract; *Py. Kr.*, decussation of pyramid; O, olivary body; *O.s.*, superior olivary body; V, motor centre of fifth; V', middle sensory centre of fifth; V'', inferior sensory nucleus of fifth; VI, nucleus of sixth nerve; *G.f.* genu of the facial nerve; VII, nucleus of facial nerve; VIII, posterior median auditory nucleus; IX, nucleus of glosso-pharyngeal nerve; X, nucleus of vagus; XI, nucleus of spinal accessory; XII, nucleus of hypoglossal nerve; *Kz*, nucleus of the funiculus gracilis; R V, roots of fifth nerve; R VI, roots of sixth nerve; R VII, roots of facial nerve.

The *optic tract* is a broad band of white fibres that passes forwards from the corpora and unites to form the chiasma, whence the true optic nerves commence.

In the *chiasma* (or commissure) half the fibres of each tract cross over in such a way that the right tract supplies

the right half of both eyes, and the left tract the left half, so that the corresponding regions of each retina are brought into connection with one hemisphere, thus securing single vision with two eyes.

If one optic tract be injured there is blindness of half of each retina (hemiopia).

In those animals whose eyes cannot act together, total decussation of the fibres takes place.

The Motor Oculi Nerves.

The **third cranial** or *motor oculi* nerves on each side arise by three bands in the posterior part of the third ventricle from the grey matter of the aqueduct of Sylvius. They supply (1) all the voluntary motion for the external muscle of the eyeball, save the superior oblique and external rectus, and the levator palpebræ superioris; (2) by the lenticular *ganglion*, the sphincter muscle of the iris; (3) and the voluntary fibres of the ciliary muscle of the lens accommodation. The fibres for this three-fold destination arise from three groups of cells. Irritation of the nerves is followed by convulsion of all the parts supplied by them. Paralysis is followed (1) by ptosis, external strabismus, diplopia, and loss of upward, downward, or inward movement from the paralysis of the eyeball and eyebrow muscles; (2) dilatation of the pupil from paralysis of the circular sphincter muscle: and (3) loss of accommodation for short distances from paralysis of the ciliary muscles.

The contraction of the pupil is generally reflex, being excited by light. The centres of the optic and third nerve are connected, so that if the retina is stimulated the third nerve acts.

When the pupil contracts, as in looking at near objects, the other parts supplied by the third nerve tend to act also, that is, the ciliary muscle and the internal rectus, as slight internal strabismus and accommodation are both needed to clearly see near objects.

The **fourth cranial** or *trochlear nerves* arise near the third pair in the fourth ventricle, and supply the superior oblique muscles. Paralysis causes slight loss of motion outwards and downwards of the eyeball.

The Trochlear Nerves.

The **fifth cranial** or *trigeminal* nerves arise on each

Fig. 170.—Part of the Fifth Cranial Nerve.

side by two distinct roots. The *sensory* or posterior root, on which is a ganglion (*Casserian*) corresponding to that in the sensory root of the spinal nerves — arises from the grey matter in the fourth ventricle (corresponding to the grey matter in the posterior horn of the spinal cord), as well as from this part of the cord down to the second cervical vertebra. The *anterior* motor root, which has no ganglion, arises from the floor of the

The Trigeminal Nerves.

fourth ventricle. Some of the motor fibres can be traced to the centre of the cortex, on the opposite side. The nerve is in three divisions, the ophthalmic, the superior, and inferior maxillary.

First Division.

The *ophthalmic division* (which receives some sympathetic fibres) supplies sensation to the upper eyelids, forehead, temple, and nose; and also, by the ciliary nerves, through the lenticular ganglion, sensation to the eyeball, a motor fibre for the dilatation of the iris, and probably vaso-motor and trophic nerves.

Paralysis or section of this division is followed by loss of sensation in the parts supplied, by loss of dilatation, and by inflammation and destruction of the cornea and eyeball.

Second Division.

The *superior maxillary* division gives sensation to the cheek, upper teeth and gums, lower eyelids, side of the nose and upper lip; and, by Meckel's ganglion, to the palate.

Third Division.

The *inferior maxillary* division contains all the motor fibres which supply the muscles of mastication. The other fibres gives sensation to the lower teeth and gums, the lower lip and jaw, and to the tongue; also to the external ear and side of the temple.

Complete section of the fifth nerve is followed by loss of sensibility in all the parts supplied by it, paralysis of muscles of mastication, and ulceration of eyeball and nasal and oral mucous membrane. The lips also move feebly, having lost sensation, which, as a rule, guides their movements, and have thus the appearance of being paralysed, though their motor nerve (the seventh) is not interfered with.

The Abducens Nerves.

The **sixth cranial** or *abducens* nerves arise from the floor of the fourth ventricle and give motion to the external rectus. Paralysis is followed by internal squint.

The **seventh cranial** or *facial* nerves arise on each side by two roots from the floor of the fourth ventricle, and supply the face with motion, and also supply the muscle of the soft palate and muscle of the middle ear. By the *chorda tympani* branch they supply the sense of taste to the front of the tongue, as well as some of the lingual muscles with motion. They also supply the parotid and sub-maxillary glands, and even aid in the secretion of saliva.

The Facial Nerves.

When paralysed (*Bell's paralysis*) one eye remains open through paralysis of the sphincter of the eye, and the cornea gets dry and opaque (but is not destroyed as in paralysis of the fifth), the hearing is impaired, and taste and smell partly gone. One side of the face is motionless and has a vacant expression, the mouth being drawn over to the opposite side by the unbalanced action of the healthy muscles and the cheek-flaps in respiration; the tongue, if protruded, is pushed over to the paralysed side.

The **eighth cranial** or *auditory* nerves arise on each side by a large anterior root from two nuclei, median and lateral, in the fourth ventricle, and a small posterior one, also from two similar nuclei. This anterior root supplies the nerves to the vestibule and canals, the posterior one to the cochlea. Fibres unite these to the cerebellum and the corpora quadrigemina. These nerves are not only for hearing but also for maintaining equilibrium.

The Auditory Nerves.

The **ninth cranial** or *glosso-pharyngeal* nerves arise from the floor of the fourth ventricle, near the two following nerves. They are nerves of taste for the posterior half of the tongue, a nerve of common sensation for the same part, and for the tonsils, soft palate, and pharynx. They supply the middle ear with sensation. They communicate with the sympathetic and tenth nerves.

The Glosso-pharyngeal Nerves.

The **tenth cranial** or *pneumogastric* nerves arise from the floor of the fourth ventricle, by an origin adjoining the ninth and eleventh. These nerves supply the pharynx with sensation and motion; by the superior laryngeal branch they supply the larynx with sensation, and by the inferior laryngeal branch with motion, and by the cardiac branch they supply inhibitory and sensory fibres to the heart. They also supply motor and sensory branches to the lungs, and branches to the stomach and liver, in which run many sympathetic fibres. They supply sensory and motor fibres to the gullet. By the depressor branch they affect the vaso-motor system, and lower the blood-pressure. Section of the pneumogastric causes death by closure of the glottis; stimulation of the superior laryngeal branch produces coughing; section of the pulmonary branch, traumatic pneumonia; and stimulation of the cardiac branch slows the heart.

The Pneumogastric Nerves.

The **eleventh cranial** or spinal accessory nerves arise on both sides, by two roots; by one root from the floor of the fourth ventricle with the ninth and tenth, and by the other from the spinal cord at the fifth cervical vertebra. The medullary roots supply the tenth nerves with their motor and inhibitory fibres. The spinal roots of the nerves supply the muscles at the side of the neck (the sterno-mastoid, and trapezius).

The Spinal Accessory Nerves.

The **twelfth cranial** or hypoglossal nerves arise from the floor of the fourth ventricle and supply the muscles of the tongue, hyoid bone, and lower jaw, with motion. Paralysis causes disturbance of speech.

The Hypoglossal Nerves.

CHAPTER XX.

SIGHT.

The organs of special sense transfer to the brain, where they are perceived by the mind or consciousness, the impressions of the various phenomena around us. Each, again, is specially adapted to respond to a certain stimulus, but may equally well be excited artificially by other stimuli.

Introduction.

A flash of light is produced by a blow on the eye, though the person be in darkness.

We will first of all consider the **organ of sight.**

I. STRUCTURE OF THE EYE.

The **eyeball** is a hollow flattened globe about one inch in diameter, of which the posterior five-sixths are composed of a tough white fibrous coat, called the *sclerotic*, and the anterior one-sixth of a transparent coat,

The Eyeball.

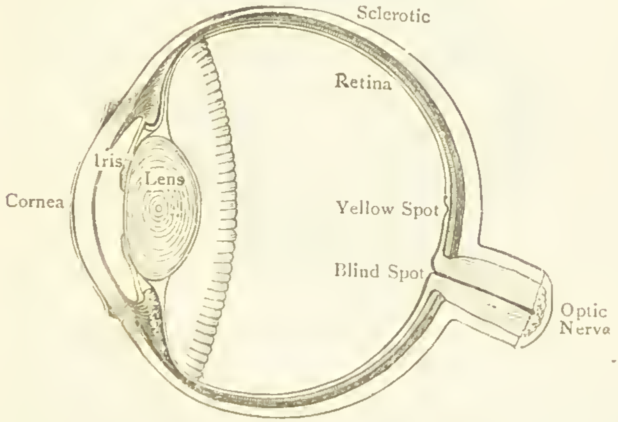


Fig. 171.—General Diagram of the Eye.

the *cornea*, which is a segment of a smaller sphere let into

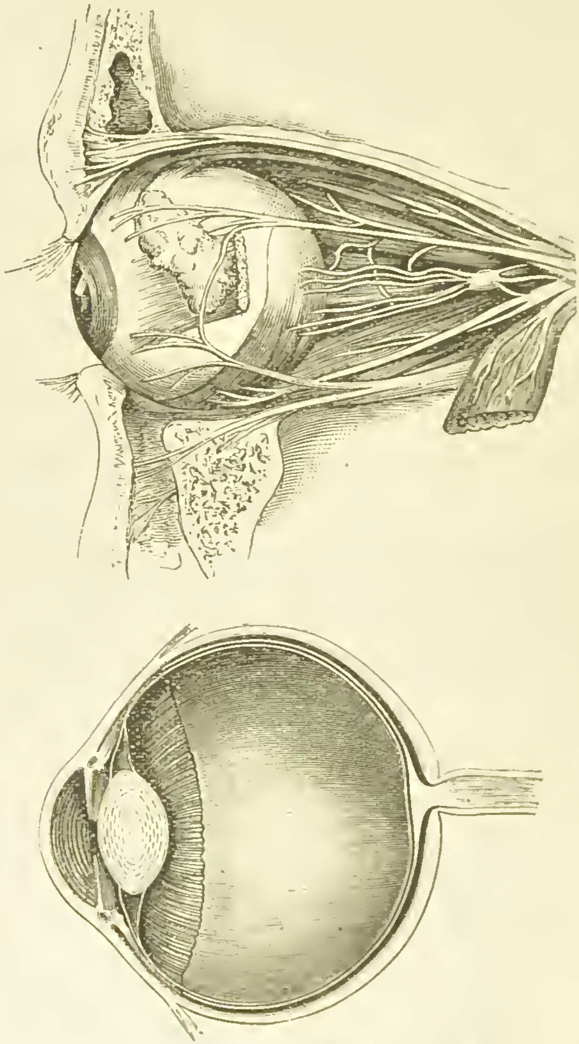


Fig. 172.—General View of Section of Eyeball, showing Nerve Supply.

the larger one of sclerotic, as a watch-glass is let into a watch. Behind the cornea is the iris, a circular muscular

curtain with a central aperture, and behind that the *lens*, the space between the cornea and the lens being filled by the *aqueous humour;* the rest of the eyeball is filled by the *vitreous humour.* The sclerotic is lined throughout its posterior two-fifths, first with the *choroid* coat, which is full of pigment blood-vessels, and then, innermost of all, with the *retina*, which is an expansion of the *optic nerve* that enters from the brain through the sclerotic, and forms the sensitive plate on which the image seen is focussed by the lens.

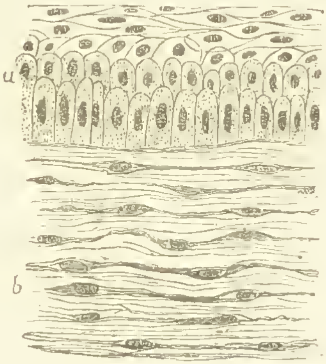


Fig. 173.—From a Vertical Section through the Anterior Layers of the Cornea.

a The stratified pavement epithelium; *b*, the substantia propria, with the corneal corpuscles between its lamellæ.

The Sclerotic.

The **sclerotic** is analogous to the dura mater in the brain (on boiling it yields gelatine, the cornea chondrin). The choroid carrying the blood-vessels resembles the pia mater, a fine membrane (the lamina fusca) lining the sclerotic may represent the arachnoid, and a space between it and the choroid containing lymph the sub-arachnoid.

The Cornea.

The **cornea** consists of five distinct layers :—

1. An outer layer, seven or eight cells deep, of stratified epithelium, corresponding with the epidermis of the skin, and like it consisting of outer cells which are flattened, then ridge-and-furrow cells, and lastly a layer of columnar cells. This epithelium is continued in a thicker stratum over the anterior third of the sclerotic, and reflected so as to line the eyelids, and is called the *conjunctiva.*

2. The anterior elastic layer of Bowman.

3. The cornea proper, consisting of a ground substance of flat bundles of finely fibrillated connective tissue, which leave spaces filled with lymph in which the branched corneal

corpuscles lie sixty deep. These corpuscles are capable of motion, and also locomotion from space to space. Then, 4, we get the posterior elastic layers, and lastly, 5, a single layer of cubical epithelial cells. The nerves are numerous, but there are no blood-vessels, except round the margin from which the cornea is nourished.

The Choroid.

The **choroid** consists of an inner capillary layer, and an outer layer of elastic tissue and pigment cells, and veins, and arteries, and ends at the anterior third of the eyeball in the ciliary processes.

The Ciliary Muscle.

The **ciliary muscle** arises round the inner margin of the junction of the sclerotic and the cornea in front, and is attached to the ciliary processes of the choroid. It is of smooth fibre in man, but striped in birds, and acts as a tensor of the choroid (drawing it forward as it contracts), and as a muscle of accommodation.

The Iris.

The **iris** consists of four layers: (1) an outer layer of a single row of epithelial cells, the continuation of those that line the cornea; then (2) the ligamentum iridis. continuous with the posterior elastic corneal layer; then (3) the muscular layers, circular within, surrounding the pupil and radiating without; and lastly (4) a layer of pigment cells or *uveal* layer.

The iris is freely supplied with blood-vessels and nerves.

The muscles are both reflex in action and smooth in fibre.

The Pupil.

The pupil *contracts* by action of the circular fibres: (1) in a bright light; (2) for near objects; (3) by drugs such as eserine (calabar bean); (4) by division of the cervical sympathetic or stimulation of the third nerve which supplies the muscle.

The pupil *dilates* by action of the radiating fibres: (1) in the dark; (2) for distant objects; (3) by drugs such as atropin; (4) by division of the third nerve or

stimulation of the cervical sympathetic which supplies the muscle.

The existence of the radiating fibres in man is denied by some, and the dilatation of the pupil is explained by the sympathetic being inhibitory in character and relaxing the circular fibres.

The size of the pupil is also affected by the state of the blood circulating in the medullary centre, and the amount of blood in the vessels of the iris; any congestion causing contraction of the pupil.

The Lens.

The **lens** lies immediately behind the iris and is held in position by a capsule composed of an elastic, transparent, homogeneous membrane. The *zonule of Zinn* is a stretched membrane that surrounds the anterior margin of the capsule and unites it with the ciliary processes of the choroid.

The lens itself is a bi-convex, transparent body, about half an inch in diameter. It is composed of elastic laminæ, in layers like an onion, which consist of ribbon-like fibre cells, hexagonal in shape and without nucleus save at the sides of the lens. The lens is harder in the middle than outside.

The Blood-vessels.

The **blood-vessels** of the eyeball are in three distinct sets: (1) for the conjunctiva; (2) for the retina (arteria centralis retina); (3) for the sclerotic, choroid, and iris, consisting of the short, long, and anterior ciliary arteries.

In the fœtus an artery runs straight through the vitreous humour, the remains of which form the canal of Stilling.

The blood-supply is very rich around the ciliary process and serves to warm the anterior part of the eyeball.

The Retina.

The **retina** is a concave membrane consisting of a connective tissue basement and layers of nerve cells formed by the expansion of the optic nerve over the posterior two-thirds of the eyeball. It is

transparent in life, but cloudy and pink after death. Opposite the centre of the lens is an elevated yellow spot, the *macula lutea*, which has in its centre a pit or depression, the *fovea centralis.* The optic nerve enters one-tenth of an inch to the inner side of this spot.

The retina consists of ten layers, seven of which are nerve structures :—

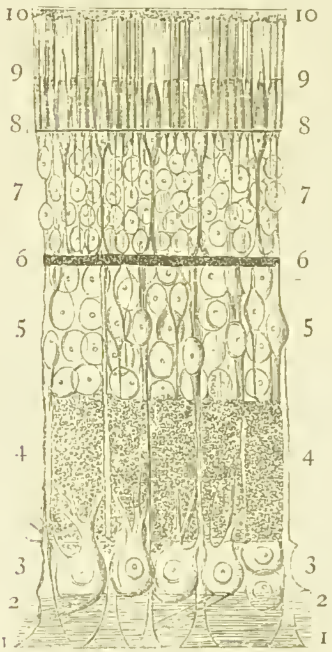


Fig. 174.—Section of the Human Retina.

Layers of the Retina.

1. *The internal limiting layer.*
2. Fibres of the optic nerve.
3. Layer of large ganglion cells.
4. Molecular layer of nerve fibrils.
5. Internal granular layer of round bipolar cells.
6. Inter granular layer of fibrils.
7. External granular layer like No. 5.
8. *External limiting layer.*
9. Layer of rods and cones.
10. *Black pigment cell layer* next the choroid coat.

In the yellow spot all the layers disappear except the cones. Here vision is most acute, and the sensitiveness of the retina varies with its distance from this spot. Thus at 5° away the sight is only $\frac{1}{4}$ as acute; at 10°, $\frac{1}{15}$; at 20°, $\frac{1}{40}$; at 30°, $\frac{1}{70}$; at 40°, $\frac{1}{200}$. Beyond this forms cannot be clearly seen. Vision at the macula is said to be direct, elsewhere on the retina indirect. Hence, to see an object clearly, we look at it, *i.e.*, focus it on the yellow spot. To every nerve fibre there are about seven cones, 100 rods,

and seven pigment cells. The rods in life contain a purplish pigment in their outer halves. It is soon bleached by light, but is restored in the dark. Its use is unknown.

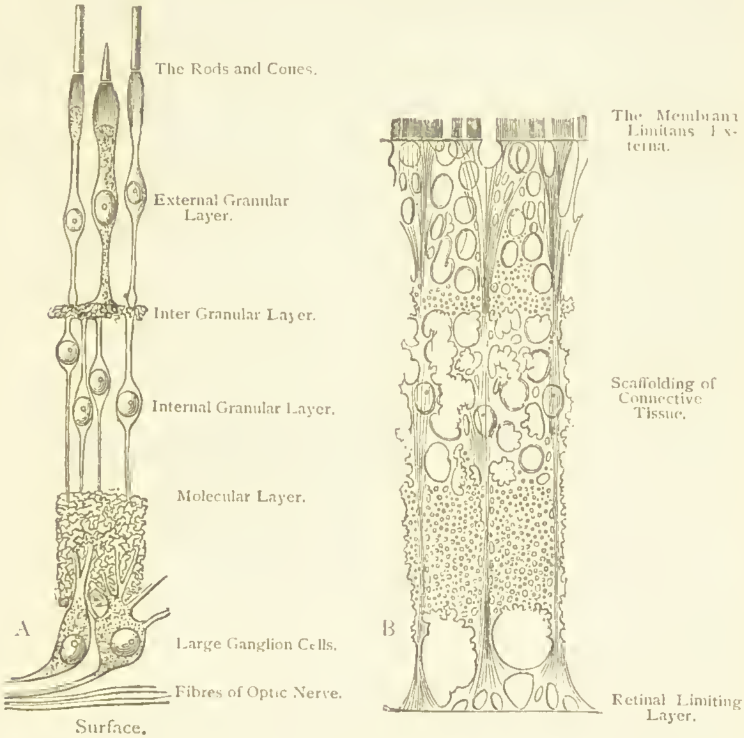


Fig. 175.—Diagram of, A, the Nervous Elements of the Retina, and, B, the Connective Tissue Substance.

The **vitreous humour** of the eyeball consists of mucous tissue and a very watery fluid. The **aqueous humour** closely resembles cerebro-spinal fluid.

The Vitreous Humour.

2. OPTICAL MECHANISM OF THE EYE.

As an optical instrument the eye is best compared to a photographic camera. The eyelid forms the cap, which,

being lifted up, the light from the object streams in through the lens, and passes across the dark chamber to be bleached upon the sensitive plate behind, which in the eye is the retina.

The Eyes and Camera.

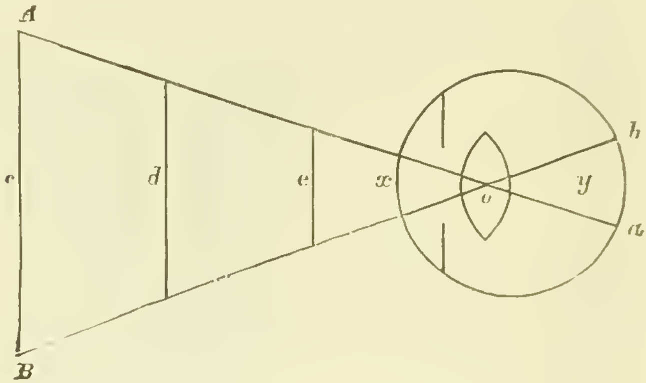


Fig. 176.—Diagram of Visual Angle.
The line A B has a visual angle x, and a retinal angle y, both of which are identical with the visual angles of any lines drawn parallel to A B, between the lines A o and B o.

If a rabbit be held before a window in a bright light for two minutes, then killed, and its eye opened, there will be seen bleached on the retina the inverted image of the window-frame. The image can be fixed with a solution of alum.

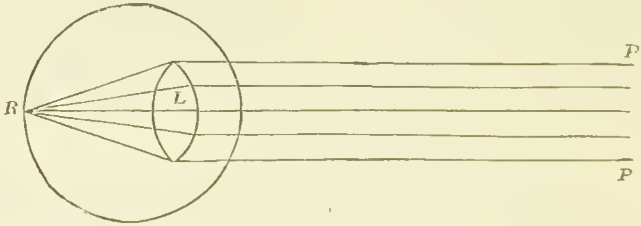


Fig. 177.—Accommodation of the Eye for Distance, Parallel Rays being brought to a Focus on the Retina. The eye is at rest, and no muscular effort is made.
L, Lens: P, parallel rays: R, retina.

One or two points must be noted as to rays of light before going into further details.

1. All rays of lights from over twenty feet are practically

parallel, and on passing through a bi-convex lens (as in the eye) are by it collected together ; a point on the other side, called the *principal focus*, a similar distance in front of the lens, is called the anterior fixed point, and it is obvious that rays from this point pass out as parallel on the other side.

The Principal Focus.

2. All rays of light proceeding from less than twenty feet distance are divergent, and hence their principal focus, after passing through the lens, recedes, until when the rays proceed from the anterior focal point it is lost altogether as the rays become parallel.

Rays for Near Objects.

Rays of light from twice the anterior focal distance are brought to a point behind the lens at twice its principal focus, but in rays from less

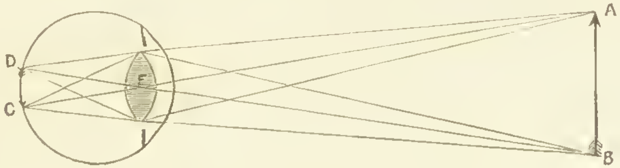


Fig. 178.—Formation of Image on the Retina.
The point B is received at D, and A at C, the image being thus reversed.

than this distance the focal point is further from the lens, while in rays at more than this distance they are nearer to the lens, until, as we have seen, at twenty feet they become the principal focal point.

Rays of light brought to a point at the principal focus diverge again after reaching it.

In passing through such a lens the image is necessarily inverted. This can be clearly seen by holding any object before the excised eye of a rabbit, when the inverted image can be perceived on the retina.

Without a lens there is no image formed ; the rays of light from the object are not collected into the focal points. In the eye the retina forms a curved sensitive plate behind the lens ; its curvature makes it very superior to the flat plate in a camera, inasmuch as the

Curved Plate.

principal focus coincides with a large area of the retina, whereas in a flat plate it only touches one part, and thus the whole object can be accurately defined instead of as, in the camera, only one part.

The normal eye is thus adapted to bring parallel rays of light (*i.e.* from objects over twenty feet) to an exact focus on the retina.

All objects less than twenty feet from the lens have to be focussed in the camera by moving the lens (by a screw) further from the plate as the principal focus is lengthened. Inasmuch as our lens is at a fixed distance from our retina, another method must be adopted. The principal focal point must, for a clear image, be at the retina. Its increased length from the lens in near objects can obviously be corrected by using a stronger or more convex lens, so as to shorten the focal distance, and this is what is done in the eye. Not that another lens is substituted, but, by what is called **accommodation**, the convexity of the lens is increased. This change is only a slight one, as the difference in the length of the focal point between rays from an object twenty feet distant and one four inches distant is only one-tenth of an inch.

Accom-
modation.

The mechanism is as follows:—The lens is highly elastic and is always kept in a state of flattened tension by the suspensory ligament, which is fixed to the ciliary process of the choroid, and the capsule of the lens. The contraction of the ciliary muscle pulls the choroid forward, relaxing the tension of the ciliary processes, and hence of the lens, particularly in front, and thus allows the anterior surface to become rounder. This can be done until it brings an object about four inches distant to a focus on the retina. The nearest point at which an object can be clearly focussed on the retina by accommodation is called the "*near point*," and varies in individuals, from three

Action of
Ciliary
Muscle.

The Near and
Far Points.

inches in children to two feet in old age, when the lens is hard and inelastic. The "*far point*" in a healthy eye is infinite distance when the rays of light are parallel.

That the anterior surface of the lens is altered in accommodation is shown by Purkinje's images.

Purkinje's Images.

If a lighted candle be held in a dark room at one side of the eye, three reflected images can be perceived by the observer.

The first is the brightest, and is erect, and is produced by the

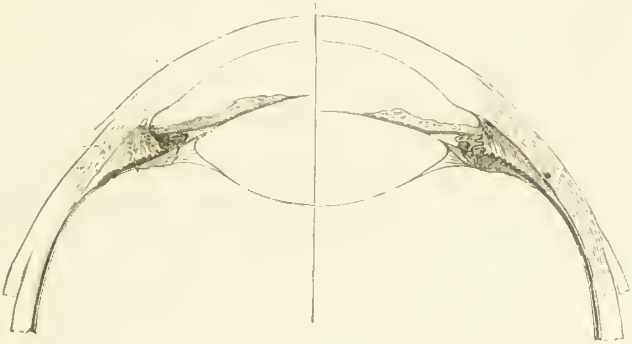


Fig. 179.—Diagram of Alteration of Anterior Lens in Accommodation.

cornea ; the second is not so bright and also erect, and is from the anterior surface of the lens ; the third is smaller, fainter, and inverted, and is from the posterior surface of the lens.

If now the eye be accommodated to look at a near object, the middle image from the anterior surface moves nearer to the corneal image, owing to the rounding of the anterior surface of the lens.

Scheiner's experiment illustrates many of the points we have touched on. If a piece of card with two holes nearer to each other than the diameter of the pupil be placed in front of the eye, and two needles held one behind each other and the eye accommodated for the near one, two inverted images of the further one are seen ; and if the right hole be covered, the left image disappears, and *vice versâ*. The reason of this is because the eye being arranged for the principal focus of the near needle to fall on the retina, and the focal distance of the further needle being much shorter, the rays of light from it have crossed and produce crossed inverted images of two needles.

At the same time that the ciliary muscle acts in accommodation two other actions take place. The *pupil contracts* and the *eyeballs converge* by the action of the internal rectus muscle, all three actions being due to the third nerve, in order that the object should be imprinted on the same part of each retina; otherwise there is *diplopia* or double sight.

Threefold Action.

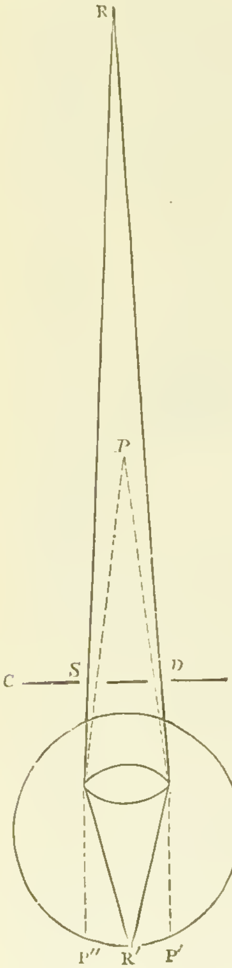


Fig. 180.—Scheiner's Experiment.

C, Card with two holes, S, left; D, right; R, further point; P, nearer point; R′, focus of distant object; P′, course of rays through dextral aperture from near point; P″, course of rays from near point through sinistral aperture.

It is obvious from this that straining in accommodation actually leads to internal squint.

The limits of distinct vision lie between the far and near points, and this constitutes the *range of accommodation.*

In some eyes various **defects** exist that have to be overcome. Some eyeballs are too long, so that the principal focus is in front of the retina and parallel rays cannot be brought to it; a focus or sub-crossing in front of the retina produces a blurred image.

Optical Defects.

This condition is called **myopia**, and is corrected by wearing concave glasses for far sight. In this eye it is obvious but little accommodation is needed, as the long eyeball gives the longer focal distance than usual.

Myopia.

Other eyeballs are too short. In these the principal focus would lie behind the retina, and the rays not having time to meet make the image of

Hypermetropic.

near objects blurred, and also increase the necessity for accommodation. This is corrected either by continual accommodation, which, by rounding the lens shortens the principal focus till it falls on the flattened

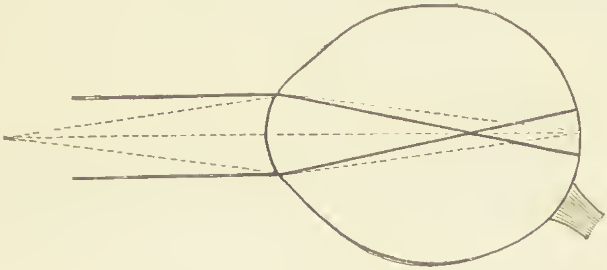


Fig. 181.—Diagram of the Course of the Rays in a Myopic Eye.

retina, or by wearing *convex* glasses, which answers the same purpose. This condition is called **hypermetropic**.

In old age the lens gets less elastic and accommodation

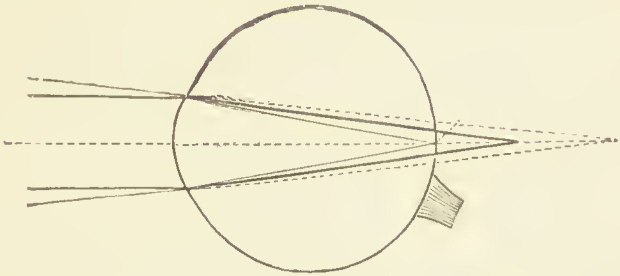


Fig. 182.—Diagram of the Course of the Rays in a Hypermetropic Eye.

more difficult, and thus the near point is inconveniently far off; hence to take the place of accommodation *weak convex* glasses are worn for near objects. This condition is known as **presbyopic**. Presbyopic.

In **astigmatism** the vertical and transverse curves of cornea and lens are not equal. This is corrected by *cylindrical* glasses. Astigmatism.

Spherical Aberration.

Spherical aberration, which consists in the over-refraction of the rays that pass through the lens, is corrected by cutting off their rays by the diaphragm or iris in front.

Chromatic Aberration.

Chromatic aberration, or the different refractions of the coloured rays that make up white light, is probably corrected by the different media (aqueous and vitreous humours) through which the light ray passes.

In passing from a denser to a thinner medium, or *vice versâ*, a ray of light is bent, but not equally. The seven colours of which it is composed have all different angles of refraction, red being least bent and violet most.

In the eye there are three curved surfaces and three different medias, but the one corrects the other, so that a ray of light continues in almost a straight line as it passes through them.

Six optical defects are said to exist in the normal eye, all of them slight :—

Natural Defects.

1. The vertical curve of the cornea is greater than the transverse, but this astigmatism is corrected by that of the shape of the lens being the opposite way. The result, however, is that we see a star, not as a circle, but as an asterisk.(*)

2. There is some chromatic aberration in the normal eye.

3. The centres of cornea and lens do not exactly coincide.

4. The media are not quite transparent.

5. Yellow pigment at the fovea centralis prevents anything being seen in its real colours.

6. There are some polarising elements.

Purkinje's Figure.

The *rods and cones* are the parts of the retina acted on by the light. This is proved by Purkinje's figure.

If in a darkened room the eye looks right ahead while a light is moved about close under the eyeball, the branching figures of the blood-vessels in the retina can be seen, showing that it must be the parts beyond these that *see ;* that is, the most external part of the retina, the rods and cones.

The cones are more important than the rods, as they

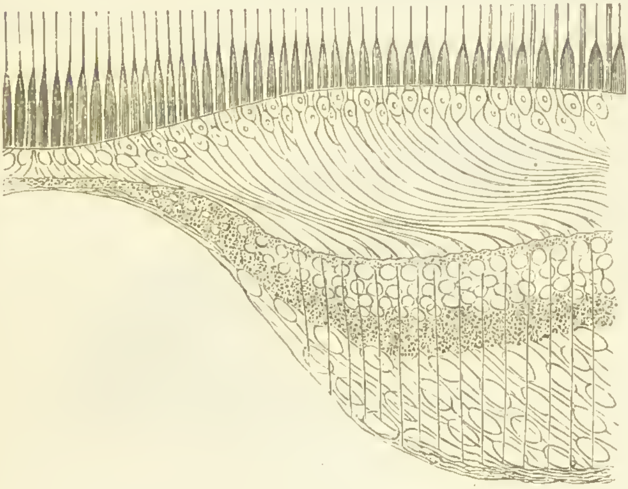


Fig. 183.—Cones at Yellow Spot.

The Cones.

alone are found in the centre of acutest vision, the fovea centralis. The blind spot of the eye is one-tenth of an inch to the inner side of this.

×

Its existence is proved by fixing the right eye on the ×, the left being closed and then the head moved slowly from the book, the eye being kept fixed on the cross, and when the image of the ball to the right falls on the blind spot it will no longer be seen. In vision the blind spot is filled up by the mind.

The Blind Spot.

The time that a visual impression remains on the retina

is one-eighth second; points of light less than $\frac{1}{12000}$ inch apart cannot be discerned as separate, this being the distance of one cone from another.

Duration of Impression.

It is probable that colour is perceived by the cones, as they are wanting in birds that fly by night and animals that live underground.

Colour Vision.

The **Young-Helmholtz theory** is that there are cones for the three primary colours, *red*, *green* and *violet;* each capable of taking up the particular ether waves that produce the colours, those of red being at

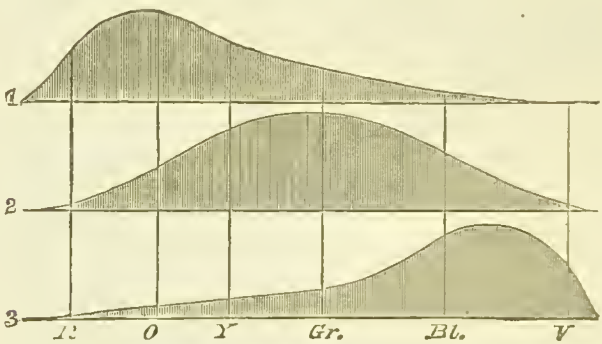


Fig. 184.—Diagram of the Three Primary Sensations of Colour. (Yeo.)
1, Red; 2, green; 3, violet

the rate of 481 millions a second, green 607, and violet 764; the waves being about $\frac{1}{50000}$ inch long. The theory accounts for the negative after-images we see. When, for instance, a red circle is gazed at long enough to exhaust the red cones where the image falls, if the eye be directed to a white surface, it appears white, except at the exhausted spot, where the red cones being useless for the time and only the green and violet active, the circle is reproduced in a violet-green.

Hering's Theory.

Hering's theory is that the perception of colour is due to the decomposition and repair of certain parts of the retina and cones. White, red and yellow produce the former effect, and

green, blue and black the latter. Neither theory, however, fully explains all the phenomena of colour vision.

Colour blindness is most common for red rays, and may be natural or produced by excessive use of tobacco. It has been found that in darkness the cones retract as well as the colour cells in the deepest layer of the retina,

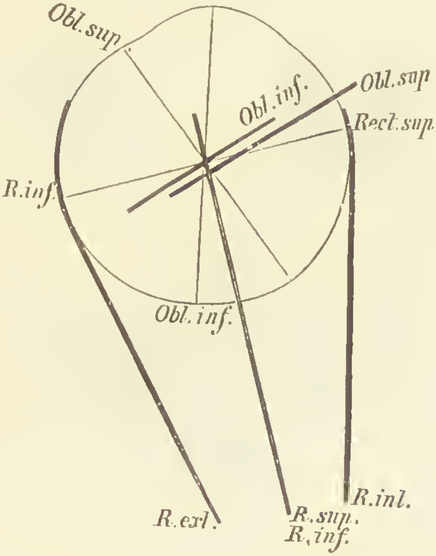


Fig. 185.—Diagram showing relative Attachments of the Ocular Muscles. The thin lines show the axes of rotation.

whereas in light they lengthen and dovetail one into the other.

The **eyeball** is moved by six muscles, four of which, the *superior*, *inferior*, *internal* and *external recti*, move it upwards, downwards, inwards, and outwards; while the other two, the *superior* and *inferior oblique* in combination with these, roll it at any angle between these four directions.

Muscles of Eyeballs.

We have **two eyes** to enable us to see things as solid

by viewing them from the different points at the same time. It is this that gives the appearance of solidity to flat pictures in the stereoscope. The two eyes also greatly increase the range of vision. Thus to see these two pictures as one it is not necessary that the two images shall fall on the same parts of each retina. If the image falls on the inner side of one retina, it falls on the

Binocular Vision.

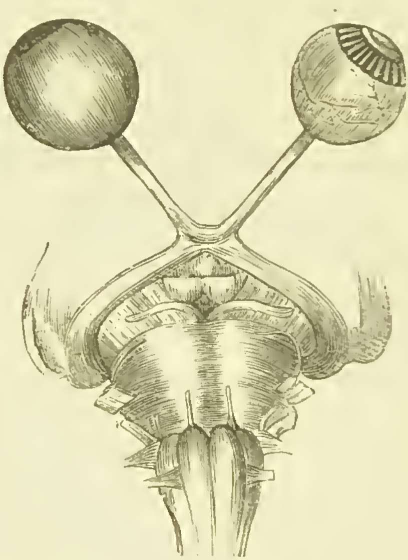


Fig. 186.—Diagram of Eyeballs and Optic Nerves and part of Pons and Medulla.

outer side of the other; and single perception of vision is secured by the complete decussation of the fibres of the optic nerve from each eye, and the supplying of every part of the outer segment of one eye with the same nerves as every similar part of the inner segment of the other. If the image be made to fall on two non-corresponding parts (as by pressing the side of one eyeball when looking at anything), two objects are seen instead of one. In those animals whose eyes, being placed laterally, are

incapable of binocular vision, the complete decussation of fibres does not take place. No full explanation of binocular vision has, however, yet been given.

The estimate of the size and distance of the objects we see is partly dependent on the size of the retinal figure and partly psychical, *i.e.* determined by our knowledge and judgment.

Thus, a child tries to grasp the moon, etc.

The *eyelids* protect the eye from excessive light, and by their movement (winking) keep the cornea moist and clean. At each movement of the upper eyelid a tear is squeezed from the lachrymal gland, which lies at the upper outer angle of the eye, across the cornea, and is carried off by two small ducts that open, one in the edge of each lid, and enter the lachrymal sac in the inner angle of the eye, and by the nasal duct descend to the inferior meatus of the nose.

The Eyelids.

The eyelids contain segments of yellow elastic cartilage and are lined with the conjunctiva. The *Meibomian glands* on the inner side secrete a fatty substance which prevents the tears from running over the edge of the lids under ordinary circumstances. The tears are alkaline, saline, and consist of 99 parts water and 1 part solids, of which half are salts.

CHAPTER XXI.

HEARING.

I. THE STRUCTURE OF THE EAR.

THE organ of hearing is an apparatus for bringing the waves of sound in contact with the auditory filaments of the auditory nerve. This organ may be divided into three parts, the *outer*, *middle* and *inner* ear.

Three Ears.

The **outer ear** consists of the *pinna* and the *auditory canal.* The **pinna** or ear proper is of but slight use in hearing, and but little is lost when it is absent. To a slight extent this acts as a reflector of sound waves into the auditory canal, and as a conductor of them, inasmuch as they are best conducted when the conducting body is vertical to them. The extraordinary shape of the ear may be accounted for in that it presents some vertical surface in every direction. The *meatus*, or canal, is rather over an inch long and secretes a little wax. It is bounded by the *tympanum*, a tough, fibrous membrane stretched at an angle of forty-five degrees from the perpendicular. This takes up every vibration of air that passes down the canal, and, the membranes being unevenly stretched, it can vibrate to vibrations as slow as thirty in the second up to rapid ones of four or five thousand. A drumhead is only adapted to one set of waves.

The Outer Ear.

The Drums of the Ear.

Behind this tympanum lies the **middle ear.** This consists of a high but shallow cavity in the temporal bone, about half an inch in height and one-eighth inch in breadth, lined everywhere with ciliated epithelium, and containing five openings, three of

The Middle Ear.

which are closed by membranes, one on the outer wall by the tympanum, and an oval and a round opening in the inner wall (the *fenestræ ovalis* and *rotunda*). The remaining unclosed openings are those leading into the mastoid cells behind and the canal of the *Eustachian tube* in front, about two inches long, leading into the upper part of the pharynx. This tube, closed

The Eustachian Tube.

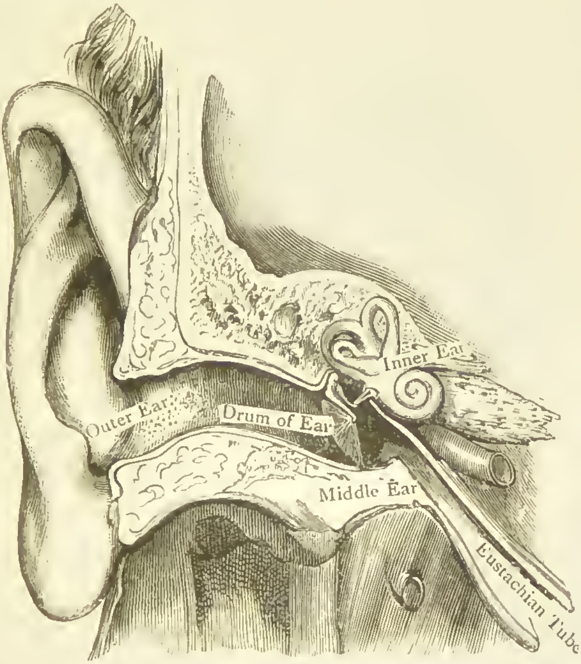


Fig. 187.—The Ear.

save when swallowing, acts as the ventilating tube of the middle ear, and insures the even pressure of air on each side of the drum which is essential to its free vibration. The tube as well as the inner surface of the drum is covered with ciliated epithelium waving towards the throat, and thus passing out any accumulated mucus.

In the middle ear are the three *ossicles*, the *malleus* or hammer, the *incus* or anvil, and the *stapedius* or stirrup.

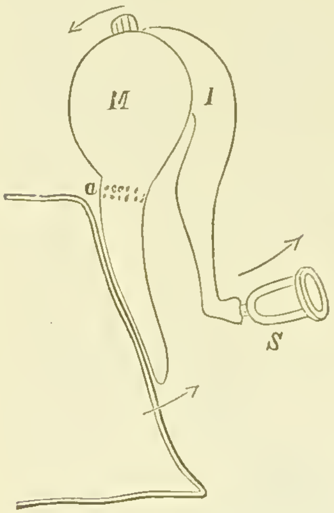


Fig. 188.—Mechanism of the Ossicula Auditus.

M, Malleus; I, incus; S, stapes; *a*, axial ligaments.

The Ear-bones.

The **malleus** is firmly fastened by its handle to the inner side of the ear drum. Its head is received into the **incus**, which is suspended from the roof. One of the feet of the anvil (which is very like a double tooth) is inserted into the wall of the cavity, and the other jointed by a small bone with the head of the **stapedius**, the foot-plate of which is firmly fixed to the membrane of the fenestra ovalis. These three bones form angular levers, by means of which the membrane of the fenestra is vibrated less extensively but more powerfully than the drum itself.

It is obvious that the drum of the middle ear receives

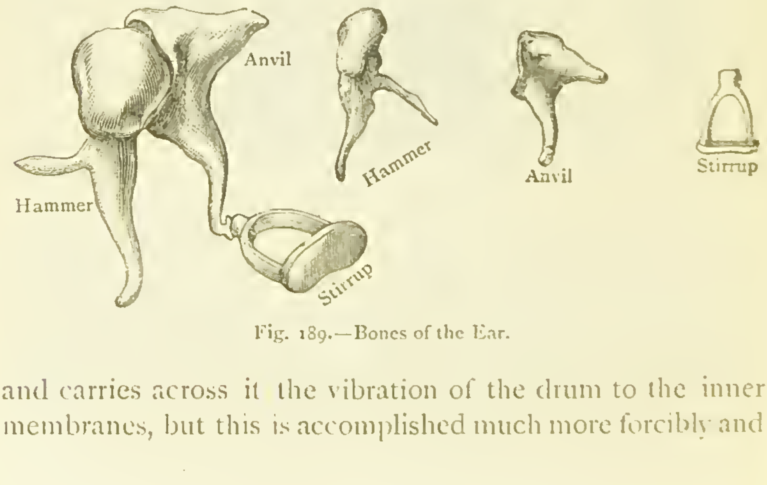


Fig. 189.—Bones of the Ear.

and carries across it the vibration of the drum to the inner membranes, but this is accomplished much more forcibly and

accurately by the chain of bones; so that, though these are not essential to hearing, they are a great aid to it. The ossicles move *en masse* and not with a mere molecular vibration. A muscle, the *tensor tympani*, can tighten or relax the drum at will, and so alter its vibrating compass. In like manner the *stapedius muscle* checks the movements of the stirrup bone.

Value of the Ear-bones.

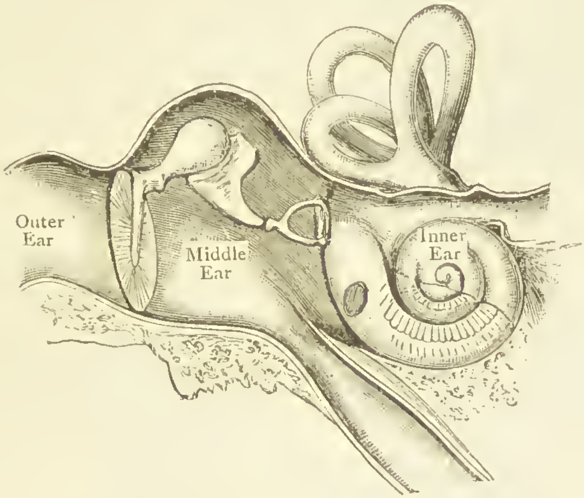


Fig. 190.—Diagram of Outer, Middle, and Inner Ears.

Behind the fenestra lies the **inner ear** or labyrinth. Immediately behind the fenestra ovalis is the vestibule, a long cavity containing fluid and having eight openings: four in the posterior and superior wall leading to the three *semicircular canals*, one in the outer wall, the fenestra, one in the anterior wall leading to the *cochlea*, and one blind tube in the posterior wall, the *aqueduct vestibuli*. The cavity is filled with fluid *perilymph*, and in the fluid floats the *membranous labyrinth*, or detached lining of the cavity, also full of fluid, *endolymph*. It consists of

The Inner Ear.

The Labyrinth

two portions, the *utricle*, which has openings leading into the membranous layers of the three canals, and also contains some nerve fibre endings and some crystalline particles, *otoliths* ; and the *saccule*, out of which the cochlea opens.

The Semicircular Canals.

The three **semicircular canals** are arranged vertically, transversely, and horizontally, and two of these have a common opening at one end, thus making five in all. They are lined throughout with the membranous canals.

Semicircular Canals.

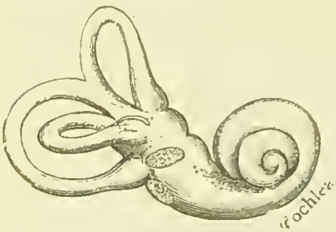


Fig. 191.—The Inner Ear Canals.

The Cochlea.

The **cochlea** is like a periwinkle shell with a spiral canal of two and a half turns divided into two by a membrane; the upper one of which, the *scala vestibuli*, communicates through the vestibule by the fenestra ovalis with the middle ear; and the lower, the *scala tympani*, by the fenestra rotunda. Besides these two openings a blind

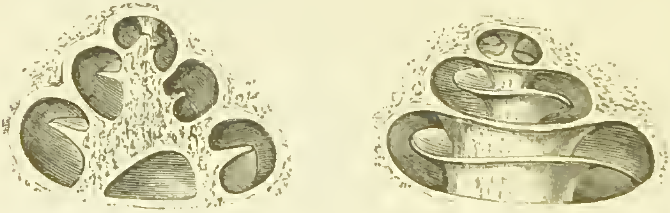


Fig. 192.—Section and Internal view of Cochlea.

branch leads from the cochlea a short distance into the bone, the *aqueductus cochlea.*

Scala vestibuli.

The **scala vestibuli** is divided into two by a second membrane (*Reissner's membrane*), and this part between it and the *basilar*

membrane is called the *scala media*. This is filled with endolymph, the other two with perilymph. In the scala media is the *organ of Corti*.

This consists essentially of pairs of cells called the

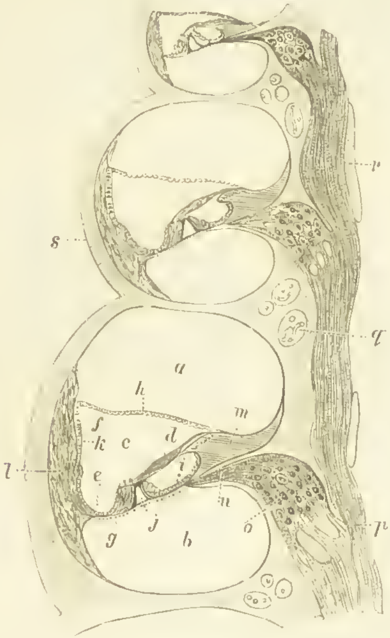


Fig 193. -From a Vertical Section through the Cochlea of a Guinea-pig's Ear, seen in the long axis of the Modiolus.

a, The scala vestibuli; *b*, the scala tympani; *c*, the scala media; *d*, the membrana tectoria; *e*, the cells of Claudius; *f*, the upper outer angle of the scala media; *g*, the region of the outer hair-cells on the membrana basilaris; *h*, the membrane of Reissner; *i*, the epithelium lining the sulcus spiralis (internus); *j*, the tunnel of Corti's arch; *k*, the stria vascularis; *l*, the ligamentum spirale; *m*, the crista spiralis; *n*, the nerve fibres in the lamina spiralis ossea; *o*, the ganglion spirale; *p*, the nerve fibres in the modiolus; *q*, channels in bone containing blood-vessels; *r*, masses of bone in the modiolus; *s*, the bony capsule.

rods of Corti, standing on the basilar membrane and leaning against each other so as to form a sort of spiral tunnel all the way up. There are actually three inner rods to every two outer, and of the outer there are 4,500. The outer one is shaped like the hammer of a pianoforte, while the inner one is like a pad

Organ of Corti.

to receive it. A membrane unites the heads of these cells with the *modiolus* or shaft in the middle and the outer wall, and is perforated with eyelet-like holes through which some three or four bristle nerve cells protrude. There is one row interior to the pad and hammer cells and three or four exterior. A second well-defined membrane (the *membrane of Corti*) rests on the surface of these bristle cells. The auditory nerve enters by the modiolus or central

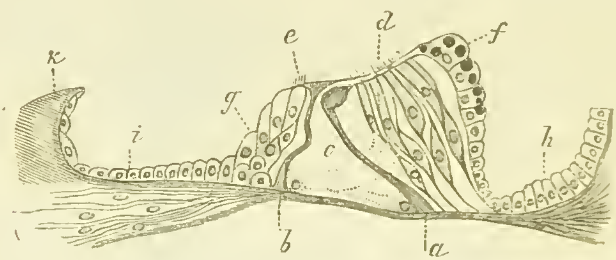


Fig. 194.—Organ o Corti of the Cochlea of a Guinea-pig.

a, Outer rod or pillar of Corti; *b*, inner rod or pillar of Corti; *c*, tunnel of Corti's arch: *d*, outer hair-cells; *e*, inner hair-cell; *f*, outer supporting cells containing fat globules: *g*, inner supporting cells; *h*, cells of Claudius; *i*, epithelial cells lining the sulcus spiralis internus; *j*, nerve-fibres: *k*, part of crista spiralis.

shaft of the cochlea and distributes branches all the way down to all these structures.

From this brief description of the three ears it will have been observed that the sound waves are transmitted by three media—solids, liquids, and gases. In the outer ear the waves are partly conducted by air and partly by the cartilage of the ear and the bones of the head. The drum of the ear passes them on partly by the air, and partly by the chain of bones of the middle ear; and by agitating the two internal membranes sets up corresponding waves of fluid in every part of the labyrinth. These, striking on the terminations of the auditory nerves, cause the perception of sound.

Course of Sound Waves.

2. FUNCTIONS OF THE EAR.

Sound is produced by waves of air varying from the bottom C on the organ, 16 per second and 64 feet long, to the shrillest sound that can be perceived by the human ear, 38,000 per second and $\frac{1}{3}$ inch long; this embraces a range of 10 octaves. Compare this with the speed and size of ether waves of light. The eye, however, has only the range of one octave of colour.

Each octave consists of waves twice as fast and half as long as the octave below.

A **musical** sound consists of waves at equal or proportionate intervals of time; a noise when they are at irregular intervals. In sound there are three factors—its *pitch*, its *intensity*, and its *quality*.

The **pitch** depends on the length and rapidity of the air waves, the **intensity** on their height, and the **quality** on the number of secondary or complementary waves that overlay the fundamental tone.

It was formerly believed that these vibrations were taken up and transferred to the auditory nerve terminals by the roots of Corti, but, as birds, which can well distinguish musical notes, have no rods, it is probably the stiff, erect hairs on the stretched strings that form the basilar membrane which have this function.

The perception of the sound is, of course, a psychical or mental act. It is believed that the special function of the vestibule is to distinguish the intensity of the sound which is transferred to the nerve hairs by the waves of the endolymph and the striking of the otoliths against them.

The semicircular canals are connected with the equilibrium of the body, and when diseased it can no longer be maintained. Injury to them does not interfere with hearing, but produces in animals a *pendulum*-like movement of the head in the direction of the damaged canal.

The cochlea undoubtedly distinguishes every vibration of sound, and transmits these, whether as speech, musical sounds, or mere noise, by the auditory nerve to the centre of hearing, and then to the cortex, where they are psychically perceived and we become conscious of them for the first time. For it is not the eye that sees or the ear that hears, but the mind of man.

CHAPTER XXII.

VOICE, SMELL, TASTE AND TOUCH.

I. PRODUCTION OF SOUND.

SOUND is produced in the larynx ; speech or articulation in the mouth.

The larynx is a long, oval box, somewhat in the shape of a short jug, without a bottom, but with a hinged lid, the hinge being forward. It is situated behind the tongue, and extends down the upper and anterior part of the throat till it joins the windpipe below. The lid at the top, the *epiglottis*, is formed of yellow elastic cartilage, and is fixed by its anterior surface to the back of the tongue. It has not much to do with the voice, but is to prevent food, solid and liquid, falling into the larynx as it passes over it on its way down the gullet behind.

The Larynx.

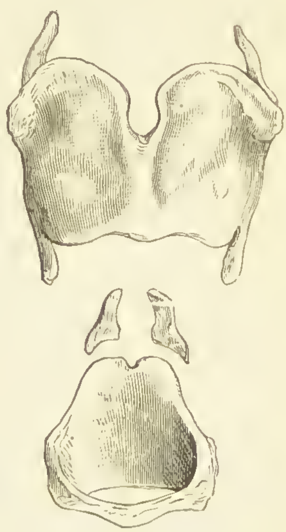


Fig. 195.—The Thyroid, Arytenoid, and Cricoid Cartilages.

The larynx itself is formed of two cartilages. The upper and larger, the *thyroid*, is like a pointed shield. It is closed in front but open behind, where it is closed by membrane and partially by two small pyramidal cartilages to which the posterior ends of the vocal cords are attached. The *cricoid* cartilage is of the shape of a

The Thyroid and Cricoid.

signet ring, with the signet behind and the narrow part in front. The *arytenoid* cartilages are fixed to the top of the cricoid.

Across the larynx, like a diaphragm divided antero-posteriorly into two plates, are the two so-called *vocal cords.* They are fixed anteriorly into the hollow of the thyroid (the *pomum Adami,* or Adam's apple), and behind are fixed to

Fig. 196.—Section of Neck showing Larynx.

the tops of the triangular pyramidal arytenoid cartilages. The cricoid and thyroid cartilages are so jointed that the thyroid can be tilted forwards, and the cricoid and arytenoids backwards, thus stretching the cords. The arytenoids can also be wheeled round on their bases in such a way that their apexes can be made to meet, thus bringing the cords in close apposition, or separated so as to make the *rima glottidis,* the space between them, of a broad triangular shape, the apex being in front and the base behind.

Just above the cords in the sides of the larynx are two *ventricles of Morgagni*, with two folds of mucous membrane above, called the *false vocal cords.* These play no part in phonation, save that by secreting mucus they serve to keep the cords moist.

The muscles that can act on the vocal cord are nine.

Muscles of the Larynx.

The pair of *crico-thyroid* muscles tilt the cricoid and thyroid apart and stretch the cords

The *thyro-arytenoid* pull them together and relax the cords.

The *crico arytenoidei postici* revolve the arytenoids so as to separate the cords.

The *crico-arytenoidei lateralis* unites them.

The *arytenoid* single muscle pulls the arytenoid cartilages still more forcibly together.

Movement of the Cords.

In ordinary respiration the cords are widely separated. In phonation they are brought together, and the expired air from the windpipe sets them in vibration, their tension and approximation determining the length and number of the air-waves thus produced, and hence the pitch of the sound.

In women the cords are one-third shorter than in men. The cords in phonation, and especially in singing, can be "stopped" like violin strings so as to vibrate over a portion of their length only at will. There are three varieties of phonation apart from other vocal sounds, such as coughing, etc.:—the *monotonous*, as in ordinary speaking, when the variety is due to articulation and the tone of the voice changes little; the *musical*, when tones are uttered with musical proportionate vibrations; and the *unmusical*, when varying tones are uttered with irregular numbers of vibrations.

Compass of Voice.

The extreme range of the voice for chest notes is from low F (42 vibrations per second) to A''' with 1,708 vibrations; the bass voice ranging generally from F (80 vibrations) to F, two

octaves up (342 vibrations); tenor from C (128 vibrations) to C'' (512 vibrations); alto F (171 vibrations) to F'' (684 vibrations); and soprano, C' (256 vibrations) to C''' (1,024 vibrations).

Falsetto.

Falsetto is produced by vibrating the edges of the vocal cords only.

The tone of the voice depends on the general construction and quality of the larynx, the pitch or the tension of the cords, the volume of sound or the amount of air forcibly expired.

2. SPEECH.

Articulation.

Speech, or articulation, consists of the moulding or shaping of the air-waves produced by the larynx, by the mouth into vowels, or the interruption of these waves by the mouth forming consonants. The combination of the two in various ways forms words.

In whispering, speech is formed in the mouth alone independently of the larynx.

Vowel Sounds.

There are *three* primary vowel sounds *a* (ah), *e*, and *u* (*oo*). In the first the mouth is funnel-shaped, the lips being widely apart. In *e* the mouth is half closed, and in *u* (*oo*) the lips are brought closer together so as to form the neck of a funnel while its wide end is backwards. The other vowels are compound sounds.

Consonants.

In consonants the air-wave is interrupted by the meeting of the lips, or lips and teeth, or tongue and teeth, or tongue and soft or hard palate. The tongue assists in speech, particularly in consonants, but is not essential to it.

3. SMELL.

Two Regions.

The nose is divided into a *respiratory* and *olfactory* region. The former includes the inferior meatus and turbinated base, and the lower

part of the middle turbinated. The region above this is the organ of smell.

The mucous membrane here is thicker, and is covered by a single layer of cubical epithelium containing a brown pigment. The respiratory region, on the contrary, is uncoloured, and clothed with ciliated epithelium, except in the nostrils, where it is squamous.

It contains tubular glands and numerous lymph follicles.

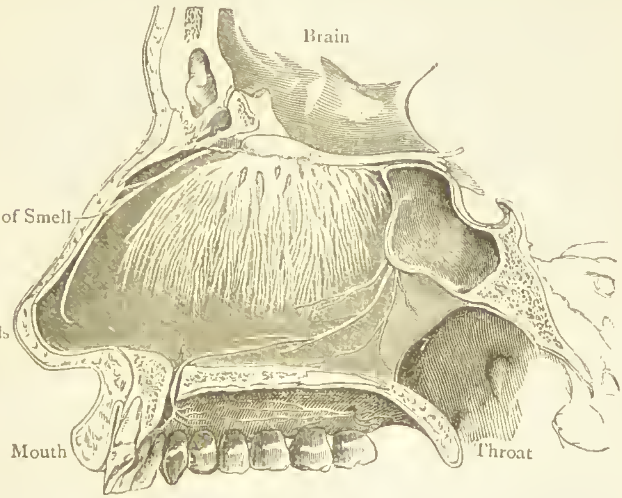


Fig. 197.—Nerves of Smell.

In it are also the terminals of the olfactory nerves, which end in olfactory cells, that are inserted between the ordinary cubical ones. The body of the cell is cone-shaped, with a large nucleus, and a rod slightly fibrillated at the end passes down to the free surface.

Organ of Smell.

These transmit olfactory sensations of gaseous odours or finely divided solids, or even odorous fluids brought into direct contact with them in the act of respiration, to the olfactory bulb of the brain, where they

Odours.

are psychically perceived. All odours must be dissolved in the mucus before they reach the olfactory cells; hence the membrane must be moist and in a healthy condition, or if it is dry, or the mucus too abundant, as in a cold, the sense of smell is impaired.

Delicacy of Smell.

The delicacy of the sense of smell is great : $\frac{3}{1000000000}$ of a grain of musk can be perceived.

Irritation of the olfactory cells or nerves will produce the sense of smell without any odour being present.

The intensity of the sense of smell depends on the size of the terminal organ and the concentration of the odour by the action of sniffing. Practice greatly improves the acuteness of smell. *Flavour* is a combination of smell and taste.

4. TASTE.

Region for Taste.

The sense of taste is located in the root of the tongue, and to some extent in the tip and margin (not the centre) of the tongue, and part of the soft palate, the uvula and the tonsils. Most of these parts are supplied by the glosso-pharyngeal nerve, which is essentially the nerve of taste.

Fig. 198.—The Tongue.

Three Papillæ.

The mucous membrane of the tongue is covered with three varieties of papillæ, *filiform*, *fungiform*, and *circumvallate*.

Filiform.

The **filiform** are the most numerous, and cover the

tongue, particularly in the middle. They may be partly for touch and partly for rasping the food against the hard palate.

2. The **fungiform** papillæ are chiefly at the sides and tips, and are small rounded projections with a constricted base, and covered with a thin layer of epithelium, and are probably organs of touch. Fungiform.

3. The **circumvallate** papillæ are about ten in number,

Fig. 199.—Filiform Papilla.

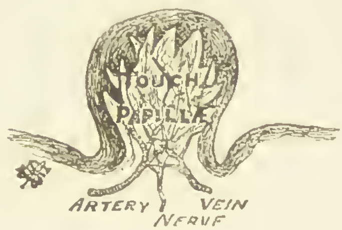


Fig. 200.—Fungiform Papilla.

arranged in a V (the point of the V being directed backwards) across the back of the tongue. They are flattened circular elevations about $\frac{1}{10}$ inch wide, surrounded with a depression or trench with an elevated ring of tissue beyond. Circumvallate.

At the base of the trench, ducts or glands secreting a viscid saliva are found, while imbedded in the sides of the trench are the *taste buds*, or true gustatory organs.

These buds are also scattered over the other regions of taste named.

Each bud or bulb is funnel-shaped, and is buried in the epithelium of the trench wall. It is composed of a series of long canoe-shaped cells, like the segments of an orange, so arranged as to leave at the surface, Taste Buds.

where they all meet, a small opening, out of which project into the trench delicate processes.

The food to be tasted is first subdivided, and then as it passes backward some part falls into these trenches, is partly dissolved, and the cell processes in contact with the solution convey the impression of the taste to the centre in the brain, along the glosso-pharyngeal nerve, which supplies these taste buds.

Method of Tasting.

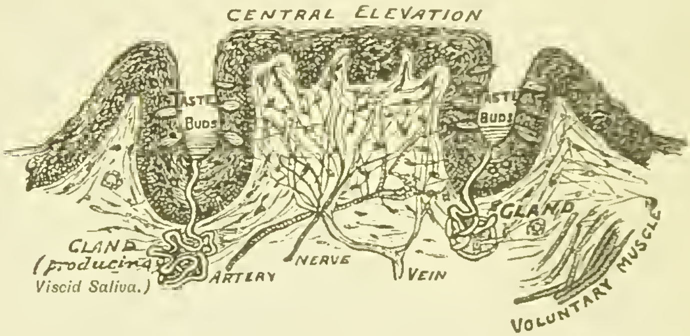


Fig. 201.—A Circumvallate Papilla.

There are four tastes—*sweet*, *bitter*, *acid*, and *saline*. Taste is aided by smell to perceive so-called flavours. Taste can discern $\frac{1}{1000}$ part of sulphurous acid in water, but smell far surpasses taste in keenness. There seems a certain harmony in taste as in smell, as well as discord, and the essence of good cooking is to obey the subtle laws of this armony, and to contrast or combine tastes with the same udgment that we contrast or combine colours.

Four Tastes.

Taste armony.

5. TOUCH.

Touch and Sensation.

The sense of touch differs from all other special senses in being distributed all over the body. Touch, indeed, is only a more delicate

and acute form of common sensation, and is due to the special modes in which certain sensory nerves terminate.

The regions where touch is acutest are the fingers, the tongue and lips, and the skin generally. The nails and teeth and the hair have all the sense of touch in a minor degree.

The **touch corpuscles** lie in the papillæ of the true

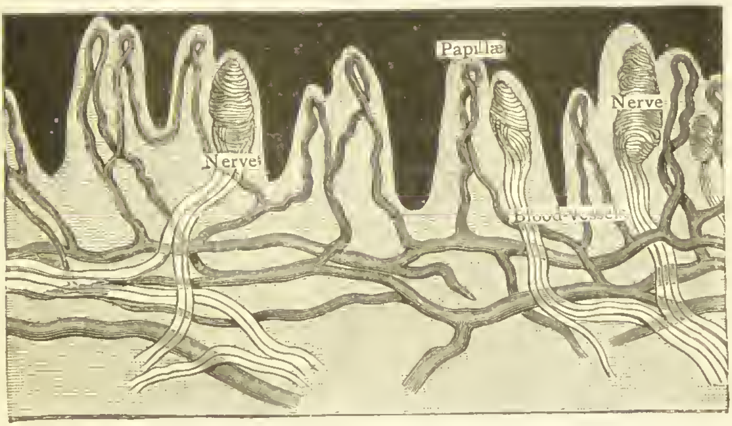


Fig. 202.—Papillæ.

skin, and are most numerous in the fingers and toes and in the palms and soles. They are oval bodies of connective tissue, with nerves wound round them and terminating in fibrils. The papillæ that contain these corpuscles contain no blood-vessels. Touch Corpuscles.

Paccinian corpuscles are oval bodies made of layers of connective tissue like an onion. The nerve in these is in the centre, and ends in an expanded extremity. They occur in the genital and some internal organs. Paccinian Corpuscles.

Krause's end-bulbs are spheroidal masses covered

with a corpuscle of connective tissue and containing cells and nerve fibres. They are found in the nose, eyelids, mouth, fungiform papillæ, the rectum, and elsewhere.

Krause's End-bulbs.

Merkel's touch corpuscles occur in the deeper

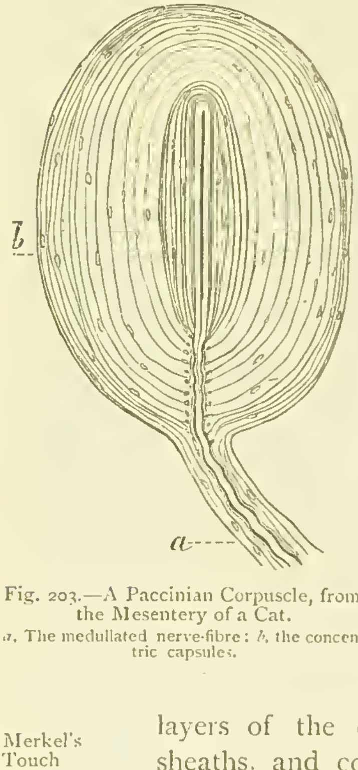


Fig. 203.—A Paccinian Corpuscle, from the Mesentery of a Cat.
a, The medullated nerve-fibre: *b*, the concentric capsules.

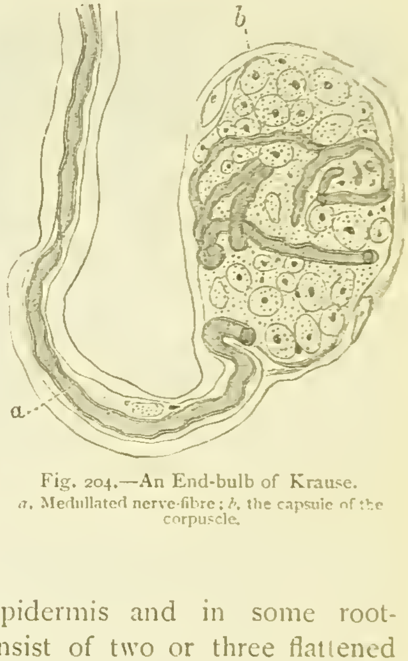


Fig. 204.—An End-bulb of Krause.
a, Medullated nerve-fibre; *b*, the capsule of the corpuscle.

layers of the epidermis and in some root-sheaths, and consist of two or three flattened cells one above another in a capsule, with a nerve fibre between them.

Merkel's Touch Corpuscles.

For the perception of touch the epidermis should be thin, but not absent. If it is wanting acute pain is felt, but the sense of touch is lost. Acuteness of touch is measured by touching the surface with the points of a blunt pair of compasses, and

Value of epidermis.

seeing the least distance at which they can be discerned by the mind as two. This is found to vary as follows:—

Tip of tongue	...	...	...	...	$\frac{1}{24}$	inch
Tip of forefinger	...	..	. .	..	$\frac{1}{12}$	,,
Under lip ...	...	...	...	...	$\frac{1}{6}$	,,
Tip of nose	...	...	...	...	$\frac{1}{4}$	,,
Palm of hand	...	...	...	...	$\frac{1}{2}$	,,
Back of hand	...	...	...	...	1	,,
Back of foot	...	...	...	...	$1\frac{1}{2}$	,,
Back of neck	...	...	...	...	2	,,
Back or thigh	...	..	...	...	$2\frac{1}{2}$	,,

Pressure is a modified sense of touch, and gives us the

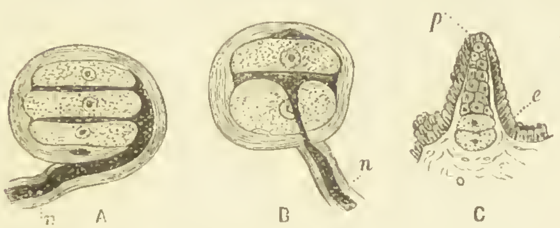


Fig. 205.—Corpuscles of Grandry in the Tongue of Duck.
A, Composed of three cells; B, composed of two cells; C, showing the development of a Grandry's corpuscle from the epithelium covering the papilla; *e*, epithelium; *n*, nerve-fibre. (Izquierdo.)

estimation of weight. Touch bulbs are arranged in groups in localities where pressure is common, and are called pressure spots, as in the soles, palms, etc. Pressure.

Pressure is felt most acutely, and difference of weight most accurately discerned, in the forehead.

Sense of temperature is another variety of the sense of touch. It is believed that temperature areas, specially sensitive to heat and cold though not to touch, exist all over the body. It is found that if the points of a compass are so near that they feel as one, they can be distinguished as two if one leg be warmed.

Common sensation differs from those we have been

describing, inasmuch as special sensations are referred to external objects, while pain, hunger, thirst, tickling, muscular sense, etc., are all referred to the body itself, though, as in pain, they may be produced by external objects. Any of these common sensations may be started by irritation of the appropriate nerves, or even by ideal centres in the brain. Thus, thinking of a rough sea-passage may produce nausea, etc.

Common Sensation.

CHAPTER XXIII.

REPRODUCTION.

I. FEMALE ORGANS.

THE female organs of generation consist of four parts—two *ovaries*, two *Fallopian tubes*, a *uterus*, and a *vagina*—arranged in the shape of a T, the ovaries and tubes forming the horizontal part, the uterus and vagina the perpendicular.

Ovaries.

The **ovaries** are oval flattened bodies about $1\frac{1}{2}$ inches $\times \frac{3}{4} \times \frac{1}{2}$, attached on each side of the uterus by a ligament (the ligament of the ovary), and slightly to one of the fimbriæ or extremities of the Fallopian tube.

Structure.

The ovary has a dense fibrous capsule (*tunica albuginea*) covered with a layer of cubical epithelium outside, and is formed of soft fibrous tissue, and may be divided into *cortical* and *central* regions. Imbedded in the cortical region are numerous small ($\frac{1}{120}$ inch) *Graafian vesicles*, containing the ova or the **female reproductive element**. Each vesicle is enclosed in a membrane (*membrana propria*) lined with nucleated cells forming the *membrana granulosa*. The cavity is filled with the ovum, composed of a delicate transparent membrane—the *zona pellucida*—and finely granular protoplasm called the *vitellus*. Imbedded in this is the nucleus or *germinal vesicle*, containing the nucleolus or *germinal spot*.

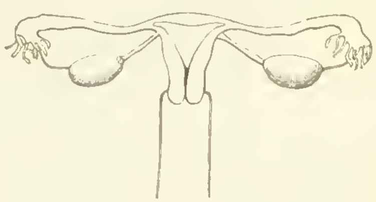


Fig. 206.—Uterus, Vagina, Ovaries, and Fallopian Tubes.

The central stroma of the ovary contains many blood-vessels and some smooth muscle fibre, and much larger Graafian vesicles, in which the ovum only occupies part of the centre, being attached by cells (called the *discus proligerus*) at one side, the rest being filled with fluid. These Graafian follicles are formed at first by a growth of the external "germ" epithelium of the ovary—which gets cut

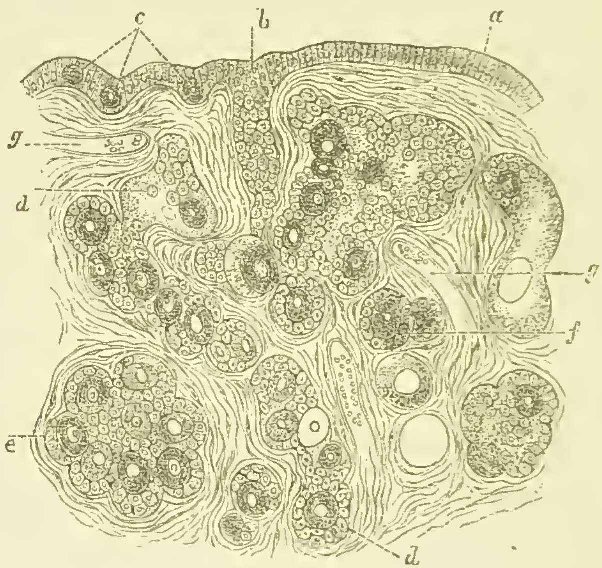


Fig. 207.—From a Vertical Section through the Ovary of a new-born Child.

a, Germinal epithelium; *b*, ovarian tube; *c*, primitive ova; *d*, longer tubes becoming constricted off into several Graafian follicles; *e*, large nests; *f*, isolated finished Graafian follicles; *g*, blood-vessels. (Waldeyer, in Stricker's Manual.)

off—and, multiplying, form cell nests and eventually the vesicle with all its layers.

As a follicle ripens it works down from the stroma into the central parts, and when it is about to burst it rises again and protrudes, and is eventually ejected at the Fallopian tube. By far the greater number of ova atrophy and disappear. There are about 60,000 in the ovary of a female infant.

Previous to puberty, although these changes are going on.

the ova never attain full development, and the ovaries are small and pale.

The **Fallopian tubes** are four inches long, and extend laterally from the upper angles of the uterus. When the tube leaves the uterus it is narrow, but gradually expands as it nears the end into a trumpet-shaped extremity, which terminates in a fine fringe which is attached by one of the *fimbriæ* to the ovary.

The Fallopian Tubes.

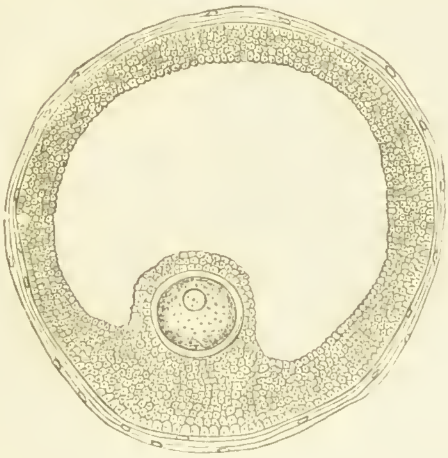


Fig. 208.—A large Graafian Follicle of the Ovary of Cat.

The follicle is limited by a capsule, the theca folliculi; the membrana granulosa is composed of several layers of epithelial cells. The ovum with its distinct hyaline zona pellucida is imbedded in the epithelial cells of the discus proligerus. The cavity of the follicle is filled with fluid, the liquor folliculi.

Its canal is lined with ciliated epithelium, and the walls are composed of fibrous and muscular tissue. The tube is only wide enough to admit a bristle as it enters the uterus. The ripened ovum passes along this tube from the ovary to the uterus.

After puberty, for a period of about thirty years, a periodic discharge takes place in women known as *menstruation*. The mucous membrane of the uterus gets swollen and turgid, and eventually is shed,

Menstruation.

wholly or in part, together with the loss of a varying amount of blood and mucus.

There is no evidence to show that the passage of ova into the tubes is specially at these times.

Corpus Luteum.

When a Graafian vessel has burst and liberated an ovum, a yellowish mass is produced called the *corpus luteum.* It is really a growth of cells of the membrana granulosa.

If the ovum that has escaped is not impregnated, the corpus luteum only lasts about a month. If it is impregnated it increases to nearly an inch in diameter, and at the ninth month is still half an inch.

The Uterus.

The **uterus** is a small triangular muscular body with the base upwards. Each side is a little over two inches long. The apex is elongated, and forms the neck or cervix which projects into the vagina. It has an outer serous coat, several layers of unstriped muscle, and an inner mucous coat, lined by a layer of ciliated epithelium and containing numerous mucous glands. In the neck of the uterus the mucous membrane is in folds. The neck terminates in two lips which form the *os uteri.*

The Vagina.

The **vagina** is the canal which, embracing the cervix uteri above, extends downwards and forwards for some five inches. It is lined with mucous membrane and squamous epithelium. Its antero-posterior walls are usually in contact, and the entrance is surrounded by a muscle that can closely contract it.

The orifice in the virgin is partly closed by a fold of mucous membrane, the *hymen.* Immediately above the opening is the *meatus urinarius* from the bladder, and above that again the *clitoris*, a small erectile organ having two small *corpora cavernosa* (as in the penis). These structures are enclosed by two vertical folds of mucous membrane, the *nymphæ*, and two external folds of skin, the *labia externa.*

2. MALE ORGANS.

The male organs of generation include the *two testes* with their ducts, the *vasa deferentia*, the two *vesiculæ seminales*, and the *penis*.

The **testes** are two oval bodies suspended in the *scrotum*,

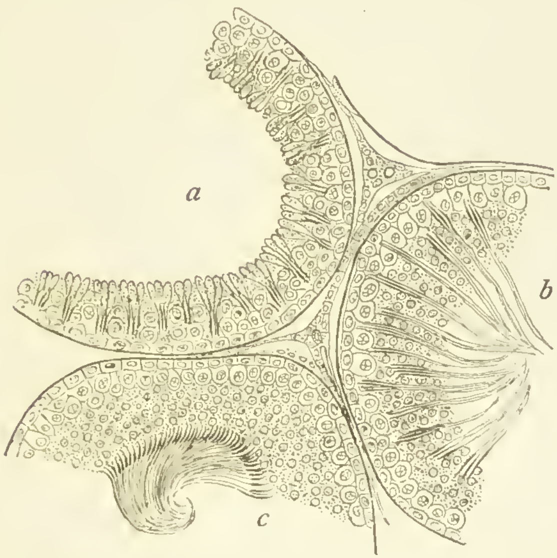


Fig. 203.—Section of parts of three Seminiferous Tubules of the Rat.
a, With the spermatozoa least advanced in development ; *b*, more, and *c*, most advanced. Between the tubules are strands of interstitial cells. (E. A. Schäfer.)

not unlike the ovaries in size, but a little larger. The testes is covered with a serous coat the *tunica vaginalis*, and a thick fibrous coat the *tunica albuginea*, which, continued inwards, partially divides the testicles vertically into two halves and also into a number of compartments or lobules. Each lobule contains several convoluted seminal tubules, each tubule being about two feet long and $\frac{1}{100}$ of an inch in diameter. They are about 800 in all,

The Testes.

and are composed of a thick basement membrane lined with layers of cubical cells. Internal to these are some large clear cells which by division produce smaller cells. These are the *spermatoblasts* or formers of the spermatozoa, which is the **male reproductive element.**

The **semen** is a gelatinous fluid with a peculiar odour.

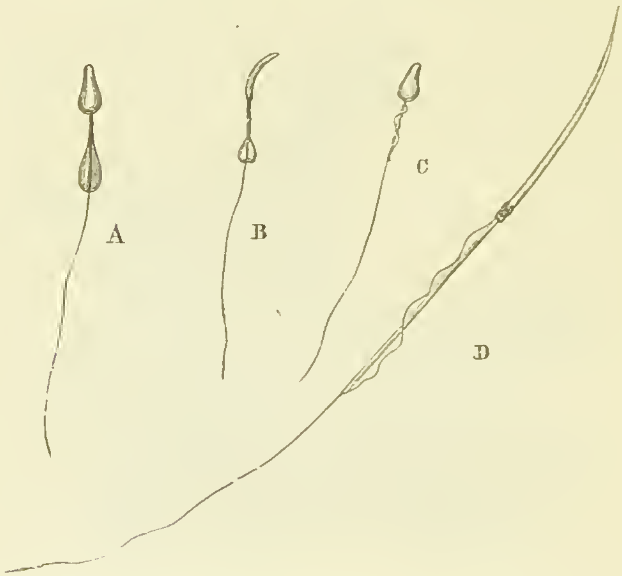


Fig. 210.—Various kinds of Spermatozoa.

A, Spermatozoon of guinea-pig, not yet completely ripe; B, the same seen sideways—the head of the spermatozoon is flattened from side to side; C, a spermatozoon of the horse; D, a spermatozoon of the newt.

It is alkaline, and composed of about three-quarter spermatozoa and a quarter clear fluid. It is 88 per cent. water.

The **spermatozoon** is a minute body consisting of a flattened head (formed out of the nucleus of the cell) $\frac{1}{6000}$ inch long, and a slender tapering tail several times as long. By the lashing of this tail, which persists for some days in suitable media, they slowly propel themselves along.

Spermatozoa.

The **seminal tubes** collect into about a dozen wide ducts, the *vasa efferentia*, which being much convoluted form the posterior tubal portion of the testes known as the *epididymis*. These gradually coalesce and enter the *vas deferens*. They are about 20 feet long, and the vasa about two feet.

Seminal Tubes.

The **vas deferens** or the excretory duct of the testes is constructed externally of connective tissues lined with mucous membrane and columnar epithelium, with unstriped muscle between.

Vas Deferens.

The two vasa pass from the scrotum by the spermatic cords, which also contain nerves and blood-vessels, and enter the *prostate gland*, and uniting with the urethra pass up the penis: the *urethra* being the common channel for the urine and the semen. Before they enter the gland they are joined by a short duct from the *vesiculæ seminales*, which are two bodies lying at the side of the bladder, each formed of a single convoluted tube that secretes a fluid that mingles with that from the testes, and thus forms the *semen*.

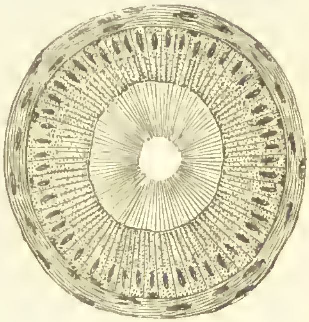


Fig. 211.—A tubule of the Epididymis in cross section.
The wall of the tubule is made up of a thick layer of concentrically arranged non-striped muscular tissue, a layer of columnar epithelial cells with extraordinarily long cilia projecting into the lumen of the tube.

The **prostate gland**, the functions of which are unknown, lies at the neck of the urinary bladder, and is pierced by the urethra, joined on each side by the vasa deferentia. It is the shape and size of a chestnut, and contains many glands which open by small ducts into the urethra.

The Prostate Gland.

The **penis** is the terminal organ, and is composed of three long masses enclosed in fibrous sheath, the two upper

being the *corpora cavernosa* and the lower the *corpus spongiosum*, through which the urethra passes. This third body is expanded at the extremity, and forms the *glans penis.*

The Penis.

The loose skin covering the glans is called the *prepuce.*

The corpora cavernosa are erectile structures containing spaces formed by fibrous tissue, which form venous sinuses, and these when filled with blood render the organ erect, rigid, and swollen.

The corpus spongiosum consists of smaller sinuses.

Cowper's glands are two small bodies the size of peas that open into the base of the urethra.

3. REPRODUCTION.

Impregnation consists in the introduction of the semen into the uterus, where the spermatozoa make their way up the Fallopian tubes and impregnate any ovum that may be being propelled down by the action of the ciliated epithelium. The impregnated ovum passes on into the uterus, and when the menstrual period comes round the soft thickened mucous membrane forms an appropriate bed or nidus for it, in which it rests, and the mucous membrane in this case is not shed, and no menstrual period occurs as long as the ovum is there. In this sense, therefore, the period is the expression of the absence of any fertilised ovum in the uterus.

Impregnation.

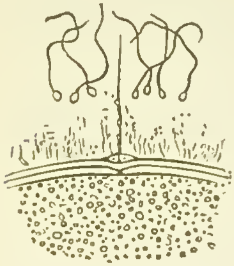


Fig. 212 —Penetration of a Spermatozoon into an Ovum, and formation of a Membrane.

The fertilisation of the ovum is produced by the entrance of one or more spermatozoa.

Fertilisation of the Ovum.

According to Balfour and many other observers, previous to impregnation the germinal

vesicle or nucleus becomes lost in the *vitellus* or yolk surrounding it. Part of it is formed into two small bodies,

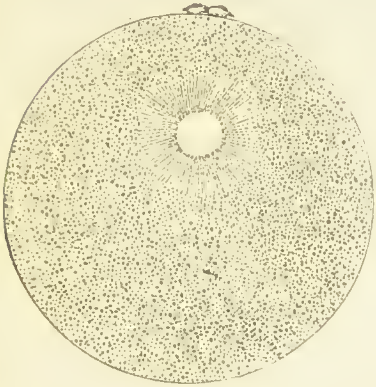


Fig. 213.—Ovum with two Polar Cells and Female Pronucleus, surrounded by Radial Striæ.

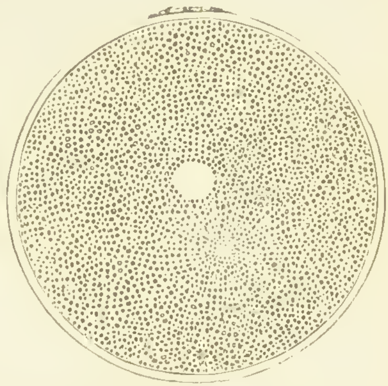


Fig. 214.—Ovum with Male and Female Pronucleus, and with radial striation of the Protoplasm around the former.

united by a rod, which partly protrude from the ovum, and are called *polar cells.* These are nipped off as small corpuscles,

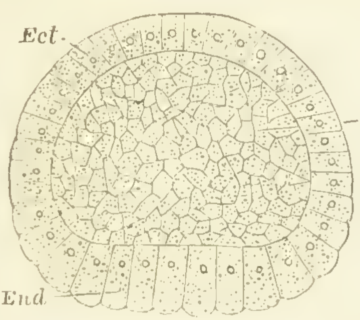


Fig. 215.—Segmentation in the Ovum of Amphioxus, Blastula stage. *Ect*, Ectoderm; *End*, endoderm; *Fh*, segmentation cavity. (After Hatschek.)

and have no further use, while the remainder forms the *female pronucleus ;* no further development being possible without impregnation. Impregnation generally takes place in the

Fallopian tube, or at times in the ovary. The spermatozoon from the semen, generally only one, passes through the vitelline membrane, and according to observations of Balfour in lower types of mammalia, the head and tail are lost, while

Fig. 216.—Antero-posterior section of the Blastoderm of the Fowl's Egg before incubation.

A, Anterior extremity; P, posterior extremity; *ex*, ectoderm; *Cs*, segmentation cavity; *n*, free nuclei in the vitellus. (After Duval.)

the part just below the head (or according to some the head itself) becomes a nucleus (the *male pronucleus*) at some

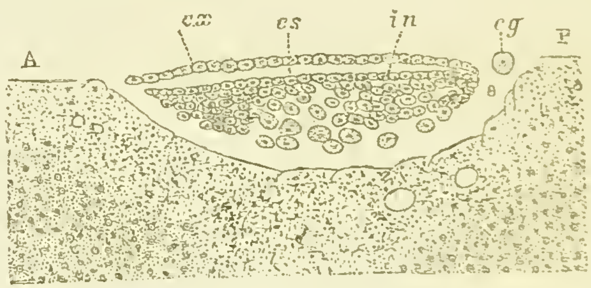


Fig. 217.—Antero-posterior section of a Fowl's Egg (not incubated).

A, Anterior. P, posterior extremity of embryo; *ex*, ectoderm or epiblast; *cs*, segmentation cavity; *in*, endoderm or hypoblast; *cg*, sub-germinal cavity with an entodermic globule at its margin.

little distance in the yolk from the female pronucleus. After a short time, by amœboid movements, the two nuclei unite and form the first *blastosphere*, which successively divides, including portions of the yolk, until the whole ovum is at first like a mulberry, and at last, by the time it reaches

the uterus, so finely divided as to be granular, each granule being in fact an embryo cell consisting of a minute quantity of yolk with a clear nucleus in the centre. The whole process so far takes about 75 hours, the ovum meanwhile enlarging through the absorption of fluid. The cells surround a hollow cavity in the centre of the ovum, called the segmentative cavity, and the hollow sphere of the ovum at this time is called the *blastodermic vesicle.* It is fully formed by the tenth day. If the ovum divides up entirely, as in man, it is called *holoblastic.* If the yolk or food remains undivided, as in birds, it is called *mesoblastic.*

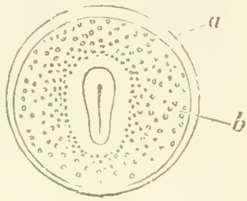


Fig. 218.—Ovum of Fowl, with Primitive Streak, surrounded by the Area pellucida, which is bounded by a line, and is pyriform, and by the Area opaca, which is oval.

a, Zona pellucida ; *b*, vitellus.

As the blastoderm enlarges, the layer of cells around the cavity become single, and at a small white spot a second layer grows inside the first till it forms a closed sac, at first pear-shaped, and then biscuit-shaped. This inner layer is called the *hypoblast*, and the upper layer the *epiblast.* At the same time numerous small hollow protuberances appear on the surface of the ovum, the villi of the *primitive chorion.* An opaque streak then appears (the *primitive streak*) in the pellucid centre (*area pellucida*), with a groove in the centre (the *primitive groove*). At the same time the hypoblast splits into two layers, the upper of which (next the epiblast) forms the *mesoblast.*

Formation of the Three Layers.

Primitive Sheath.

Fig. 219.—Diagram showing the gradual folding off of the Embryo, which comes to be seated on an eminence, and has a curved form.

a, Zona pellucida ; *b*, vitellus ; *c*, embryo ; *d*, *e*, folds of amnion.

We have thus three layers :—

The **epiblast**, out of which is formed the central nervous system, and the whole of the external tissues ; the **mesoblast**, from which are formed most of the organs and structures of the body, including bone and muscles, the connective tissue, reproductive and excretory organs ; and the **hypoblast**, which lines the whole of the digestive tract and all its glands.

Structures Formed by the Three Layers.

In the epiblast a groove now appears, the *medullary groove*, the sides of which rise up (the *laminæ dorsales*) and

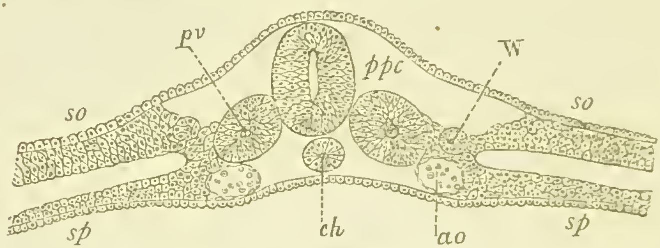


Fig. 220.—Diagram showing early differentiation of parts in Blastoderm. *ch*, Chorda dorsalis ; *pv*, provertebræ : *W*, Wolffian body ; *ao*, aorta ; *ppc*, pleuro-peritoneal cavity ; *so*, somatopleure ; *sp*, splanchnopleure.

gradually unite, forming the *neural tube* or *central canal* of the spinal cord, the cells inside which become the ciliated epithelial lining. At its anterior end the medullary or neural tube has four dilatations representing the *fore brain* (hemispheres), *mid-brain* (corpus quadrigemina), *hind brain* (cerebellum), and *after brain* (medulla); these grooves get folded and twisted so as to form the head. The rest of the epiblast forms the skin.

In the mesoblast a cord is formed below the medullary groove, round which the bodies of the vertebræ are formed like a string of beads. The mesoblast at this point splits into two layers, the upper uniting with the epiblast form the *somatopleure* or parietal layer, while the inner and the hypoblast form the *splanchnopleure* or visceral layer. The space between them

Splitting of the Mesoblast.

becomes the pleuro-peritoneal cavity. This division ceases at the medullary groove. So far the embryo lies flat on the surface of the yolk, but by degrees the layer surrounding it appears to be tucked in at the head and tail, ends and sides, thus giving it a convex shape and raising it till it is like a canoe upside down, out of the well of which is the stalk connecting the hollow head part or *head gut*, and the *hind gut* with the mass of yolk outside.

This duct is called the *vitelline duct*, and the yolk the

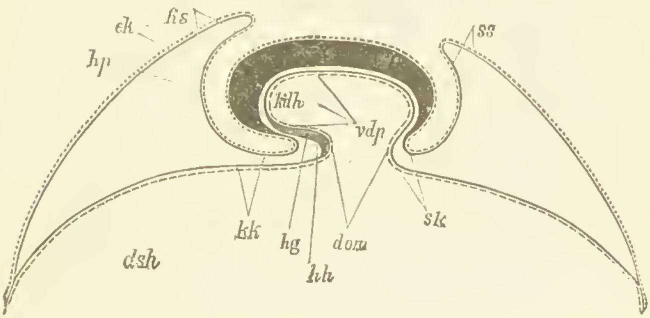


Fig. 221.—Diagram to show the mode of Origin of the Amnion.

hp, Somatopleure; *ks*, head fold of amnion; *ss*, tail fold of amnion; *ek*, epiblast; *kk*, head cap; *sk*, tail cap; *dsh*, cavity of the yolk sac; *dom*, ductus omphalo-mesentericus or omphalo-mesaraicus; *kdh*, pharyngeal or anterior portion of intestinal cavity; *vdp*, hypoblast lining the cavity of the intestine; *hg*, rudiment of heart; *hh*, part of pleuro-peritoneal cavity.

umbilical vessel; the rest of the duct is eventually the umbilicus. The folding down of the visceral side plates thus enclosing a cavity filled with yolk, completes the first part of the formation of the embryo.

Vitellus Duct.

We have now a neural canal above a vertebral layer, and a larger body canal in front communicating with an umbilical vessel outside.

At this period, four clefts or visceral arches appear in the side of the head opening into the fore-gut, while a slight depression indicates the oro-nasal aperture. Posteriorly a similar depression forms the anus.

Branchial Clefts.

During this formation of the embryo the somatopleure

rises up at each side over the back of the embryo, and meeting forms the *amniotic sac*, the inner layer of mesoblast forming the *true amnion*, the outer of epiblast the *false amnion*, there sometimes being a cavity between containing "*false* water." This cavity fills with fluid, so that eventually the embryo floats in it.

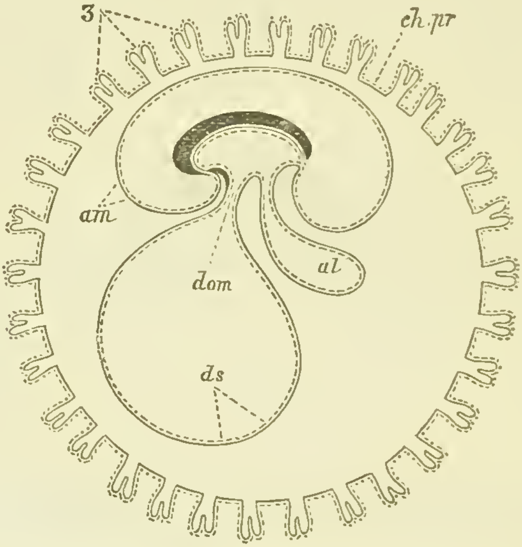


Fig. 222.—Diagram to show the complete Formation of the Amnion.
am, Amnion; *al*, allantois; *dom*, umbilical duct; *ds*, umbilical vesicle; 3, villi; *ch. pr*, chorium primitivum.

This amniotic fluid is largely formed of fœtal urine.

At this time an internal projection grows in the hind gut into the pleuro-peritoneal cavity towards the vitelline duct through which it passes, and grows up, alongside of the umbilical vesicle, spreading itself between the layers of the amnion.

This is called the *allantois*, and at its origin eventually forms the urinary bladder.

The Allantois.

Blood-vessels form at an early stage which carry the contents of the umbilical vesicle to the embryo.

The outer layer of the amnion, the vitelline membrane of the ovum, and the allantois all blend into one, which is called the *true chorion.*

We have already spoken of the villi of the chorion. They are at first hollow, and as blood-vessels are formed in the allantois they extend into these cavities.

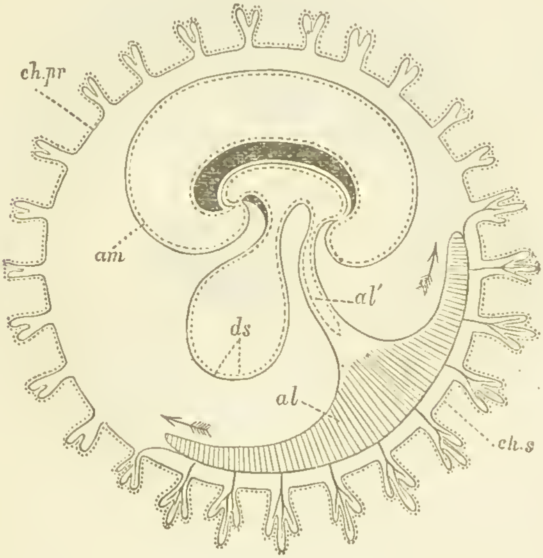


Fig. 223.—Diagram to show the Formation of the Allantois.
ch.pr, Primary chorion; *ch.s*, secondary chorion; *am*, amnion; *ds*, remains of yolk sac *al*, allantois; *al'*, neck of allantois.

To understand the further steps, we must consider the condition of the uterus at this time.

The Placenta.

The mucous membrane of the uterus is lined with mucous glands lined with ciliated epithelium. This mucous membrane thickens at pregnancy as at menstruation, and becomes more vascular, and its superficial layer becomes the *membrana decidua*, or the part eventually shed with the ovum. The cavity of the uterus soon becomes

filled with secreted fluid with nucleated cells. When the ovum reaches the uterus it is imbedded in the decidua, part of which grows up round the ovum and forms the *decidua reflexa*, the *decidua vera* being the superficial lining of the

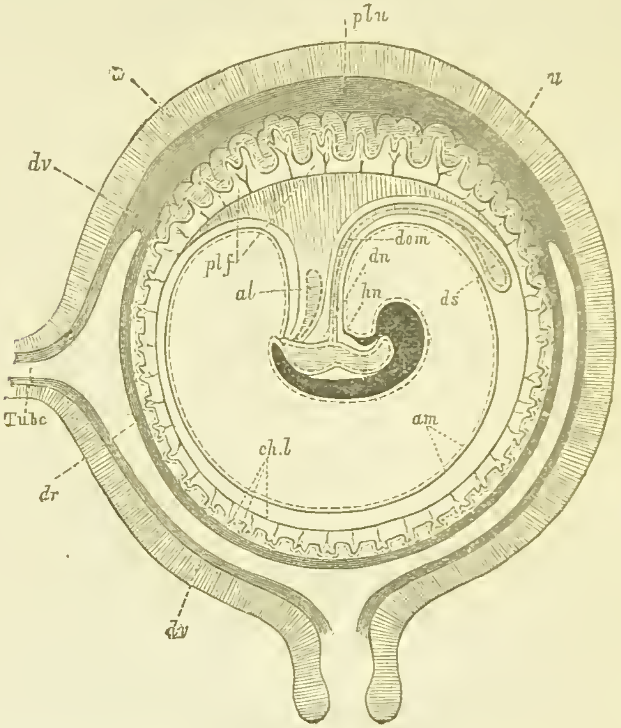


Fig. 224.—Diagram to show the Formation of the Placenta.

u, Uterus; *dv*, decidua vera; *dr*, decidua reflexa; *ch.l*, chorion; *am*, amnion; *al*, allantois; *ds*, vitelline duct and sac; *plf*, placenta fœtalis; *plu*, placenta uterina; *dom*, ductus omphalo-mesentericus; *hn*, the point of junction of the amnion with the skin; *dn*, the cavity of the amnion.

uterus. As the ovum gradually fills the uterus these two come in contact and coalesce. The *decidua serotina* is that part of the decidua where the placenta is formed as follows. Part of the deeper mucous membrane where the ovum is attached becomes hollowed out by spaces that communicate with both arteries and veins, and the villi on this side of the ovum

push through the decidua serotina into them. Over the rest of the surface of the ovum they disappear.

We thus get the *placenta* formed, essentially consisting of a fœtal part, the outgrowth of the ovum, like the fingers of gloves, full of fœtal blood-vessels dipping into the maternal

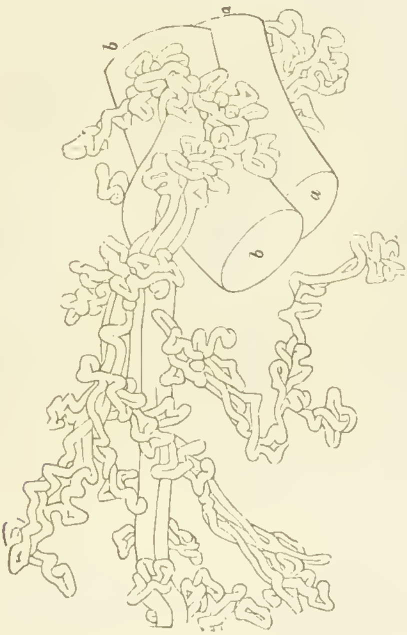


Fig. 225.—The Villi of the Fœtal portion of a Mature Human Placenta × 100 diam.; the capillaries are filled with injection.
a, artery; *b*, vein.

part, which are sinuses full of the parent's blood. A double interchange thus takes place. The fœtus is supplied with arterial blood by the mother, and the mother receives the used products of the fœtus.

It is thus that a fœtus can infect a mother with syphilis or other poisons.

The *umbilical cord* connects the placenta with the fœtus,

and in late fœtal life only certain traces of its original formation, which, in addition to the two arteries and vein from the embryo, include the layer of the amnion, the umbilical vesicle (never bigger than a pea in man) and its duct, and the remains of the allantois. The cord is nearly twenty-four inches long, and the three blood-vessels in it make about forty turns. *Wharton's Jelly* surrounds the arteries.

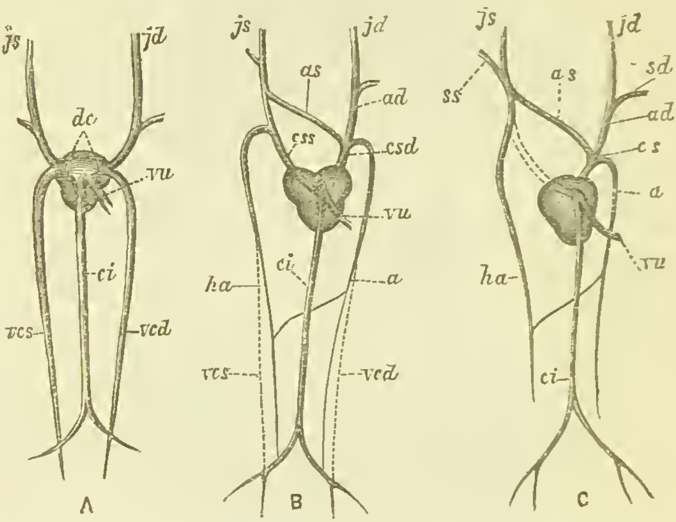


Fig. 226.—Diagram to show the Early Stages of the Second Embryonic Circulation. (Seen from behind.)

js, Left jugular; *jd*, right jugular; *dc*, ductus Cuvieri; *ci*, cava inferior; *vcd*, right cardinal vein; *vcs*, left cardinal vein; *csd*, superior right vena cava; *css*, superior left vena cava; *vu*, umbilical vein; *a*, azygos vein; *ha*, hemi-azygos vein; *ad*, right innominate; *as*, left innominate; *sd*, right subclavian vein; *ss*, left subclavian vein; *cs*, cava superior.

The fœtal circulation when established is as follows:—The blood of the fœtus passes along the two hypogastric arteries, through the two umbilical arteries, along the cord to the placenta. Then the pure blood is returned along the umbilical vein to the inferior vena cava by the *ductus venosus*. It then enters the right auricle, and, guarded by the Eustachian valve, the great mass of blood (instead of descending into the right

Fœtal Circulation.

ventricle and thence to the lungs, as it does when the pulmonary circulation is established) passes through the *foramen ovalis* direct into the left auricle, thence to the left ventricle, and by the aorta to the hypogastric arteries. The blood from the superior vena cava coming downwards does not pursue this course, but through the right auricle descends into the right ventricle to the pulmonary artery, and then by the *ductus arteriosus* into the aorta.

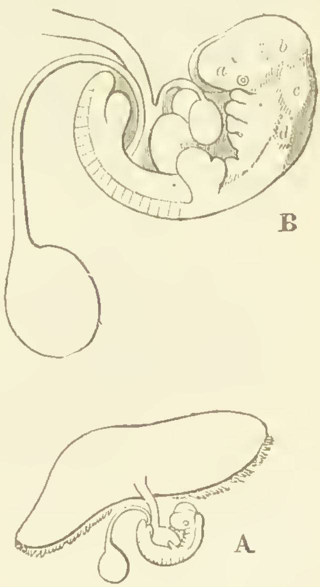


Fig. 227. Diagram showing the curved Form of the young Embryo: A, natural size; B, magnified. The head is seen to be sharply curved downwards. In the fore and lower part of the head is the eye; immediately below which are the visceral arches. The vitelline sac is seen reduced in size and attached by a long pedicle to the body of the embryo.

After birth the hypogastric arteries are obliterated and become the lateral ligaments of the bladder, the remains of the allantois (the *urachus*) forming a median ligament. The umbilical vein becomes the *ligamentum teres* of the liver, and the ductus venosus and arteriosus and foramen ovalis are all closed.

The Mammæ.

The **mammary glands** may be noticed here as connected with reproduction. Each gland has about twenty ducts opening on the nipple. As they pass into the gland they branch like a tree, one large branch to each lobe of the gland, the lobes being united by connective tissue. During lactation only, the fine terminals of these ducts communicate with the secreting acini. Each acinus consists of a basement membrane with a circular layer of nucleated secretory cells inside, which by fatty metamorphosis produce,

together with numerous oil globules, the milk, the lumen being filled with it. The ducts are lined with cubical epithelium. The nipple and areola are pigmented more abundantly during pregnancy.

Each acinus is surrounded by a network of capillaries, and many lymphatics, from which the milk appears to be partly prepared. The acini are not formed much before puberty, and degenerate at the menopause.

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